# UNIT - I

## Cell is the Basic Unit of Life

The cell is the fundamental structural, functional, and biological unit of all known living organisms, including bacteria, fungi, plants, and animals. The concept of the cell as the basic unit is central to biology and is encapsulated in the modern cell theory

**Cell Theory**

The cell is considered the basic unit because it is the smallest entity that can perform all the essential activities of life:

- **Structure:** All organisms are composed of one or more cells
- **Function:** Metabolic processes (energy production, nutrient uptake, waste removal) occur within cells
- **Reproduction:** All cells arise from pre-existing cells through cell division
- **Heredity:** Genetic information is stored, expressed, and passed on to the next generation within cells

### 1. Bacteria (Prokaryotes)

Bacteria are **prokaryotic** organisms, meaning they are single-celled and lack a membrane-bound nucleus and other complex organelles [1, 3].

- **Basic Unit:** The *entire organism* is a single cell. This single cell is self-sufficient and capable of independent existence and reproduction [1].
- **Structure:** They have a simple internal structure with genetic material (nucleoid region), ribosomes, cytoplasm, a cell membrane, and usually a cell wall [3].
- **Function:** The bacterial cell performs all life processes within its single boundary:
    - **Metabolism:** Breaking down nutrients for energy (e.g., cellular respiration, photosynthesis in some cases) [3].
    - **Growth:** Increasing in size and dividing [3].
    - **Reproduction:** Asexually, typically through binary fission [3].

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### 2. Fungi (Eukaryotes)

Fungi are **eukaryotic** organisms. They can be single-celled (like yeast) or multicellular (like mushrooms and molds) [1, 4].

- **Basic Unit:** The cell is the fundamental unit in both forms.
    - **Unicellular Fungi:** (e.g., yeast) the single cell performs all life functions independently [4].

    - **Multicellular Fungi:** (e.g., mushrooms) are composed of many cells organized into filaments called hyphae, but individual cells still carry out essential metabolic functions [4].
- **Structure:** Fungal cells have a true nucleus, membrane-bound organelles (mitochondria, endoplasmic reticulum, etc.), a cell membrane, and a cell wall typically made of chitin [4].
- **Function:**
    - **Organization:** The cellular structure allows for specialization in multicellular forms, such as cells dedicated to reproduction (spores) or nutrient absorption [4].
    - **Metabolism:** Fungal cells are heterotrophs, absorbing nutrients from their environment [4].

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### 3. Plants (Eukaryotes)

Plants are complex, **multicellular eukaryotic** organisms.

- **Basic Unit:** The cell is the building block of all plant tissues and organs (roots, stems, leaves, flowers) [1, 5].
- **Structure:** Plant cells are highly specialized and characterized by unique features:
    - **Cell Wall:** A rigid outer layer made primarily of cellulose that provides structural support [5].
    - **Chloroplasts:** Organelles where photosynthesis occurs, allowing the cell to produce its own food using sunlight [5].
    - **Large Central Vacuole:** A membrane-bound sac that stores water and maintains turgor pressure [5].
    - **Nucleus and other organelles:** Standard eukaryotic machinery [5].
- **Function:** While part of a larger, integrated organism, the plant cell maintains its basic functional identity:
    - **Photosynthesis:** Occurs within individual chloroplasts in specific cells (e.g., mesophyll cells) [5].
    - **Specialization:** Cells differentiate into various tissues (epidermis, vascular tissue like xylem and phloem, ground tissue) to perform specific roles within the plant [5].

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### 4. Animals (Eukaryotes)

Animals are complex, **multicellular eukaryotic** organisms.

- **Basic Unit:** The cell is the fundamental unit of structure and function for all animal tissues and organ systems (nervous, circulatory, muscular, etc.) [1, 6].
- **Structure:** Animal cells are typically more flexible than plant or fungi cells because they lack a rigid cell wall.

- They have a cell membrane, nucleus, mitochondria, ribosomes, and other typical eukaryotic organelles [6].
- Unique structures include centrioles and lysosomes [6].

- **Function:**
  - **Metabolism:** Animal cells obtain energy primarily through cellular respiration [6].
  - **Differentiation:** Cells show extensive specialization into diverse types (e.g., nerve cells transmit signals, muscle cells contract, red blood cells carry oxygen) [6]. Despite specialization, each cell maintains basic life functions and operates as the smallest living unit of the organism

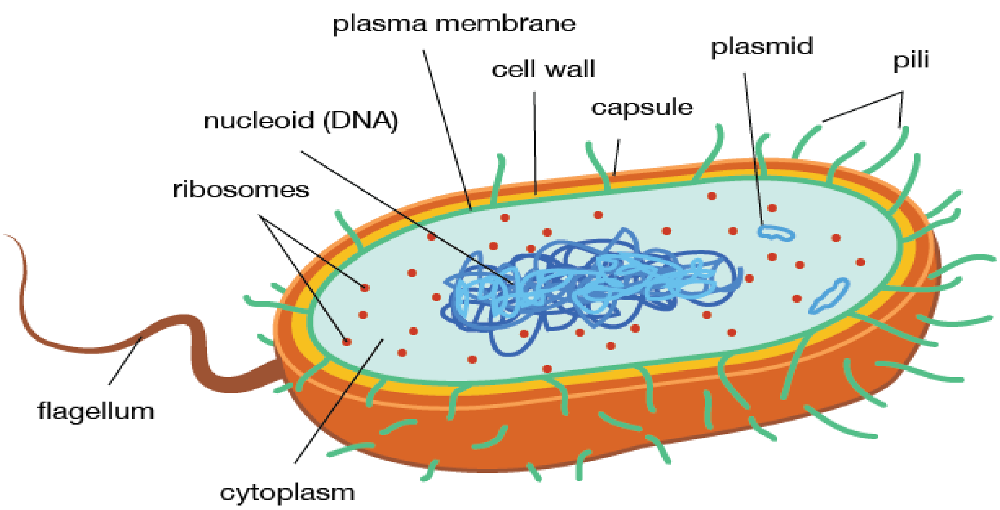
## 1.2 ULTRA STRUCTURE OF PROKARYOTIC CELL

Prokaryotic cells, the structural units of bacteria and archaea, are characterized by the absence of a nucleus and other membrane-bound organelles. Their key features include a cell envelope, cytoplasm, nucleoid, ribosomes, and sometimes appendages like flagella and pili.

### Key Features of Prokaryotic Cells

- Small in size (0.1 – 5 µm)
- No membrane-bound nucleus
- Circular DNA in nucleoid region
- Ribosomes (70S)
- Mostly unicellular (e.g., Bacteria and Archaea)

## Ultra-Structure (Detailed Components)




### 1. Cell Envelope *(3-layered structure)*

- **Glycocalyx**: Outermost layer; protects against desiccation and phagocytosis.
  - *Types*: Capsule (thick, organized) or Slime layer (thin, loose)
- **Cell Wall**: Provides shape and rigidity; made of **peptidoglycan** (murein).

- **Plasma Membrane**: Semi-permeable; controls entry/exit of substances; lipid bilayer with proteins.

### 2. Cytoplasm

- Jelly-like fluid inside the cell.
- Contains enzymes, nutrients, ions, and ribosomes.
- **No membrane-bound organelles**.

### 3. Nucleoid

- Irregular region containing **circular DNA** (single, double-stranded).
- Not enclosed by a membrane.
- Contains genetic material for cellular functions.

### 4. Plasmids

- Small, circular, extra-chromosomal DNA.
- Carries non-essential genes (e.g., antibiotic resistance).
- Can replicate independently.

### 5. Ribosomes (70S)

- Site of protein synthesis.
- Smaller than eukaryotic ribosomes (80S).
- Free-floating in cytoplasm.

### 6. Inclusion Bodies

- Storage granules (e.g., glycogen, phosphate, sulfur).
- Not membrane-bound.

### 7. Mesosomes

- Infoldings of plasma membrane.
- Role in DNA replication, respiration, and cell division.

### 8. Flagella *(if present)*

- Long, whip-like structure for locomotion.
- Composed of **flagellin**.
- Structure: Basal body, hook, filament.

### 9. Fimbriae and Pili

- **Fimbriae**: Short, hair-like; help in surface attachment.

- **Pili**: Longer; involved in conjugation (transfer of DNA).

### ? Examples of Prokaryotic Cells

- **Bacteria**: E.g., *E. coli*, *Bacillus subtilis*
- **Archaea**: Extremophiles (live in harsh environments)

# Prokaryotic Cell – Plasma Membrane

### ◆ Definition:

The **plasma membrane** (also called **cell membrane**) is the **innermost layer of the cell envelope** in prokaryotic cells. It is a **semi-permeable membrane** that surrounds the cytoplasm and controls the movement of substances in and out of the cell.

### Structure:

- **Phospholipid Bilayer**:
  - Composed of two layers of **phospholipids**.
  - Each phospholipid has a **hydrophilic head** (water-loving) and **hydrophobic tails** (water-fearing).
- **Proteins**:
  - **Integral proteins**: Embedded in the membrane.
  - **Peripheral proteins**: Attached to the surface.
  - Function in transport, communication, and structural support.
- **No sterols** (like cholesterol in eukaryotic membranes), but some bacteria (e.g., Mycoplasma) have **hopanoids** that stabilize the membrane.

### Functions:

1. **Selective Permeability**:
   - Regulates entry and exit of ions, nutrients, and waste products.
2. **Site of Metabolic Activities**:
   - Unlike eukaryotes, many vital processes occur at the plasma membrane in prokaryotes, such as:
     - **Respiration**
     - **Photosynthesis** (in photosynthetic bacteria)
     - **ATP production**
3. **Anchorage Site**:
   - For enzymes and structures like **flagella** and **mesosomes**.
4. **Cell Division**:

- Involved in DNA replication and cell division processes.

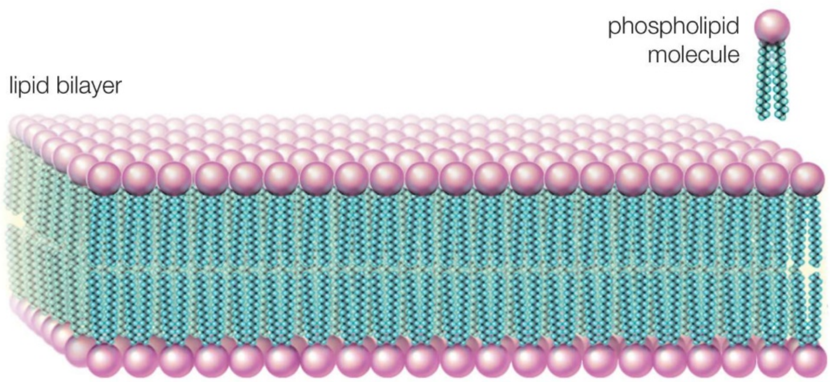
# Models of Plasma Membrane

## 1. Introduction

- The **plasma membrane** is a selectively permeable barrier that surrounds the cell, controlling the movement of substances in and out.
- Composed mainly of **lipids**, **proteins**, and **carbohydrates**.
- Over time, different models have been proposed to explain its **structure and function**.

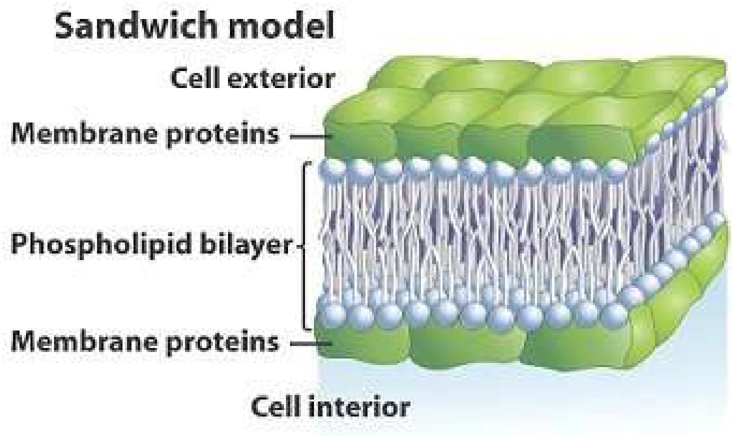
# Major Models

### A. Lipid Bilayer Model (Gorter and Grendel, 1925)



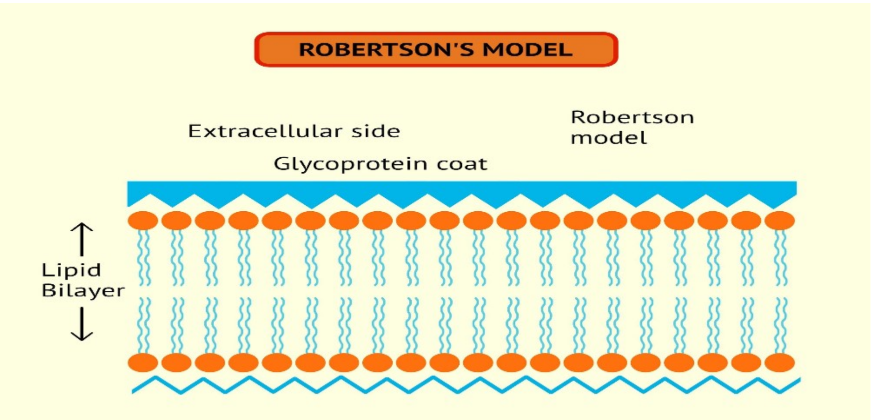

- **Proposed by:** Evert Gorter & François Grendel.
- **Basis:** Study of lipid extraction from red blood cells.
- **Key Points:**
    - Membrane is made up of a **bilayer of phospholipids**.
    - Hydrophilic heads face **outwards** towards water.
    - Hydrophobic tails face **inwards**, away from water.
- **Limitations:** Does not explain protein arrangement or membrane function.

### B. Sandwich Model (Danielli and Davson, 1935)



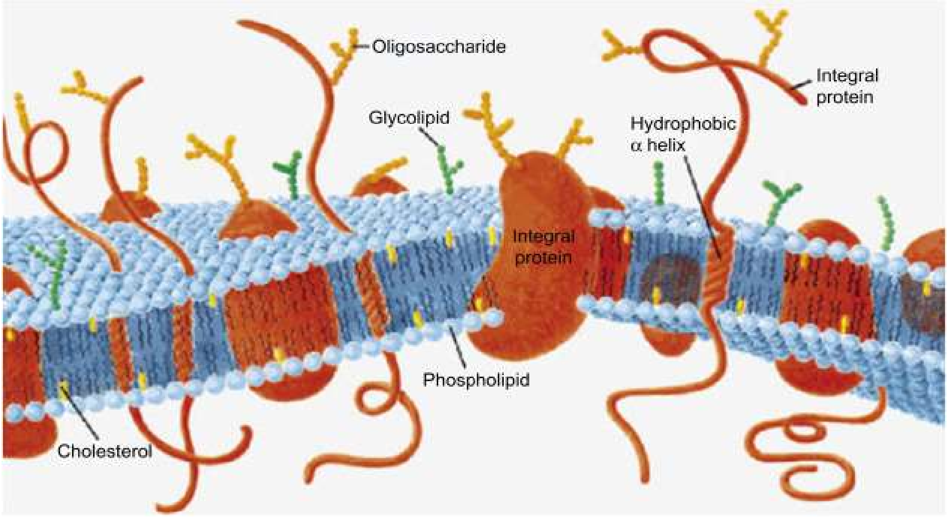

- **Proposed by:** James Danielli & Hugh Davson.
- **Structure:**
  - Lipid bilayer **sandwiched** between two layers of globular proteins.
  - Proteins provide **mechanical stability**.
- **Limitations:**
  - Could not explain membrane flexibility, permeability, and protein mobility.
  - Later evidence (electron microscopy) showed proteins are not continuous layers.

### C. Unit Membrane Model (Robertson, 1959)




- **Proposed by:** J. David Robertson.
- **Structure:**
  - All biological membranes have a **common trilaminar appearance** (seen in EM).
  - Two dark layers (proteins) separated by a light layer (lipid bilayer).
- **Limitations:**
  - Did not explain the **dynamic nature** of the membrane.
  - Could not account for variability in membrane composition.

### C. Fluid Mosaic Model (Singer and Nicolson, 1972)




- **Proposed by:** S. Jonathan Singer & Garth Nicolson.

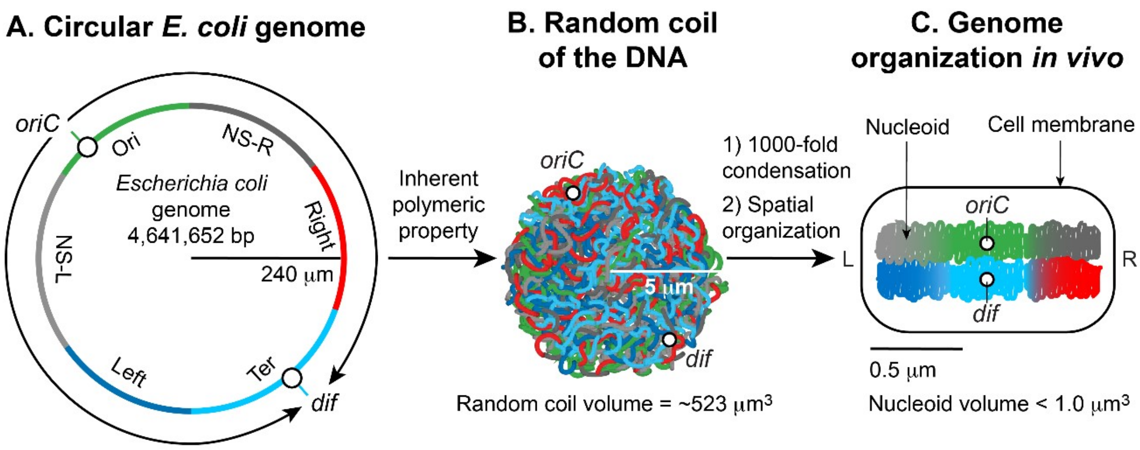
- **Structure:**
  - **Phospholipid bilayer** acts as a fluid matrix.
  - Proteins are embedded (integral) or loosely attached (peripheral) and can move laterally.
  - Carbohydrates are attached to lipids (glycolipids) or proteins (glycoproteins).
- **Features:**
  - **Dynamic** – lipids and proteins move freely.
  - **Asymmetrical** – inner and outer leaflets differ in composition.
  - Selectively permeable.
- **Advantages:**
  - Explains membrane flexibility, self-healing, transport, and signaling.

# NUCLEOID

## Definition

- The **nucleoid** is an irregularly-shaped, membrane-free region inside a **prokaryotic cell** that contains the cell's genetic material (DNA).
- It is functionally equivalent to the **nucleus** of eukaryotic cells but lacks a nuclear membrane.

## Location and Structure




- Found in **bacteria** and **archaea**.
- Not enclosed by a membrane – DNA is in direct contact with the cytoplasm.
- Shape and size vary depending on cell type and stage of growth.
- DNA is usually a **single, circular, double-stranded molecule**.
- Often associated with RNA and nucleoid-associated proteins (NAPs) that help in DNA packaging.

### Composition

1. **DNA** – Usually circular; contains the entire genetic blueprint.
2. **RNA** – Mainly mRNA, rRNA, and tRNA during transcription.
3. **Proteins** – Nucleoid-associated proteins (e.g., HU, IHF, H-NS) help in:
    - DNA bending and compaction
    - Gene regulation
    - Protection from damage

### Functions

- Stores genetic information for cell growth, reproduction, and survival.
- Coordinates **DNA replication**, **transcription**, and **gene expression**.
- Provides structural organization of DNA without a membrane.

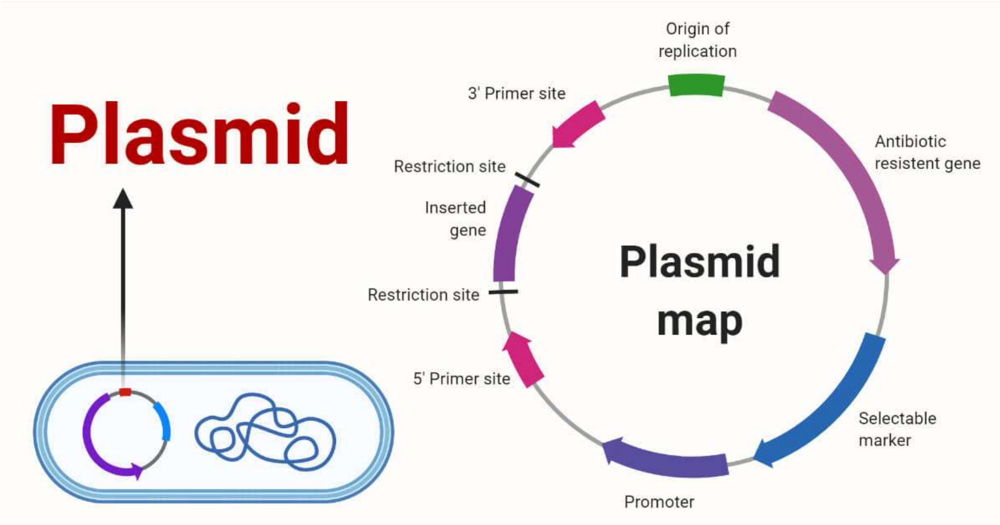
# Plasmids

### Definition:

Plasmids are small, circular, double-stranded DNA molecules found in bacteria (and sometimes in archaea and eukaryotes) that replicate independently of the chromosomal DNA.

- **Nature:**

- Extrachromosomal genetic elements
- Non-essential for basic survival but provide adaptive advantages
- Self-replicating




## Characteristics

1. **Shape & Size:**
   - Usually circular (some are linear)
   - Size ranges from **1 kb to >200 kb**
2. **Replication:**
   - Autonomous replication
   - Uses origin of replication (**Ori site**) distinct from the bacterial chromosome
3. **Copy Number:**
   - **High copy number plasmids** (e.g., ColE1) → 50–100 copies per cell
   - **Low copy number plasmids** (e.g., F plasmid) → 1–5 copies per cell
4. **Transferability:**
   - Some plasmids are **conjugative** (contain genes for transfer)
   - Others are **non-conjugative**
   -

### Types of Plasmids (Based on Function)

1. **Fertility (F) plasmids:**
   - Carry **tra genes** for bacterial conjugation
   - Example: F plasmid in *E. coli*
2. **Resistance (R) plasmids:**

    - Carry antibiotic resistance genes
    - Example: R100 plasmid
3. **Col (Colicinogenic) plasmids:**
    - Produce bacteriocins (proteins toxic to other bacteria)
    - Example: ColE1
4. **Degradative plasmids:**
    - Allow degradation of unusual substances (e.g., toluene, pesticides)
    - Example: TOL plasmid in *Pseudomonas putida*
5. **Virulence plasmids:**
    - Carry genes for pathogenicity
    - Example: Ti plasmid in *Agrobacterium tumefaciens*

## Applications in Biotechnology

- **Gene cloning** (as vectors for recombinant DNA technology)
- **Protein production** (e.g., insulin production)
- **Genetic engineering of crops** (Ti plasmid in plant transformation)
- **Gene therapy** (plasmid-based DNA vaccines)
- **CRISPR delivery systems**

## Advantages for Host Bacteria

- Antibiotic resistance
- Heavy metal resistance
- Metabolic versatility
- Competition advantage through bacteriocin production

## Important Examples

- **pBR322** → Cloning vector in *E. coli*
- **pUC series** → High-copy-number cloning plasmids
- **Ti plasmid** → Plant genetic engineering
- **R100 plasmid** → Multiple antibiotic resistance

# Ultra Structure Of Eukaryotic Cell

**What is a Eukaryotic Cell?**

Eukaryotic cells have a nucleus enclosed within the nuclear membrane and form large and complex organisms. Protozoa, fungi, plants, and animals all have eukaryotic cells. They are classified under the kingdom Eukaryota.

They can maintain different environments in a single cell that allows them to carry out various metabolic reactions. This helps them grow many times larger than the prokaryotic cells.

**Characteristics of Eukaryotic Cells**

The features of eukaryotic cells are as follows:

1. Eukaryotic cells have the nucleus enclosed within the nuclear membrane.
2. The cell has mitochondria.
3. Flagella and cilia are the locomotory organs in a eukaryotic cell.
4. A cell wall is the outermost layer of the eukaryotic cells.
5. The cells divide by a process called mitosis.
6. The eukaryotic cells contain a cytoskeletal structure.
7. The nucleus contains a single, linear DNA, which carries all the genetic information.

**Structure Of Eukaryotic Cell**

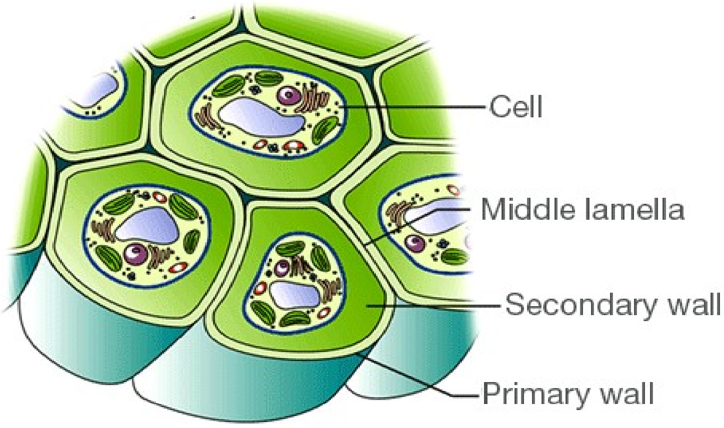
The eukaryotic cell structure comprises the following:

## Cell Wall

The cell wall is the outer covering of a cell, present adjacent to the cell membrane, which is also called the plasma membrane. As mentioned earlier, the cell wall is present in all plant cells, fungi, bacteria, algae, and some archaea. An animal cell is irregular in its shape and this is mainly due to the lack of cell wall. The compositions of the cell wall usually vary along with organisms.

The plant cell wall is generally arranged in 3 layers and composed of carbohydrates, like pectin, cellulose, hemicellulose and other smaller amounts of minerals, which form a network along with structural proteins to form the cell wall. The three major layers are:

1. Primary Cell Wall
2. The Middle Lamella
3. The Secondary Cell Wall




### Primary Cell Wall

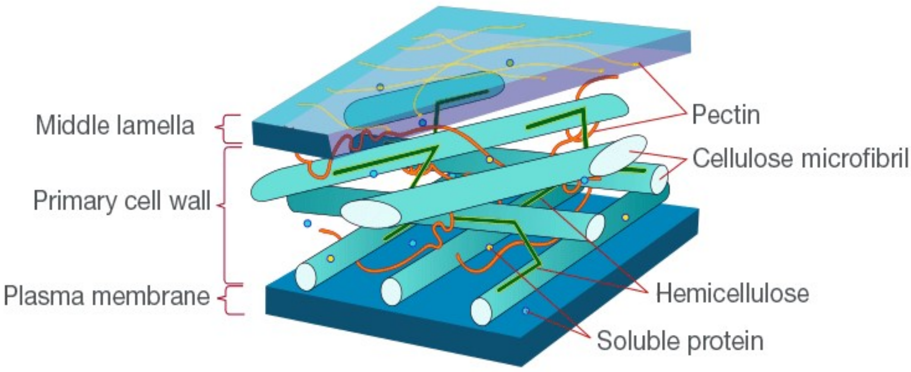
The primary cell is situated closest to the inside of the cell and is the first-formed cell wall. It is mainly made up of cellulose, allowing the wall to stretch for the purpose of growth. Several primary cells contain pectic polysaccharides and structural proteins. It is also comparatively permeable and thinner than the other layers.

### Middle Lamella

The middle lamella is also the outermost layer and it acts as an interface between the other neighbouring cells and glues them together.  This layer primarily consists of pectins. However, other substances such as lignin and proteins can also be found.

### Secondary Cell Wall

The secondary cell wall is formed inside the primary cell wall once the cell is completely grown. Some types of cells (especially the cells of xylem tissues) consist of cellulose and lignin and these provide additional rigidity and waterproofing. Also, this layer provides the characteristic rectangular or square shape to a cell. It is also the thickest layer and permits permeability.




## Pits

- In the secondary cell wall, pits are the unthickened areas or depressed areas.
- A pit consists of a pit cavity or pit chamber and pit membrane.

- The pit membrane consists of the primary cell wall and middle lamella.
- The pit membrane is permeable.
- So pit helps in rapid translocation of materials between two adjacent cells.

**Tertiary cell wall**

- In some plant cells, there is the presence of another cell wall beneath the secondary cell wall. It is known as the tertiary cell wall.
- The morphology, chemistry, and staining properties of the tertiary cell wall are different from the primary and secondary cell walls.
- In the tertiary cell wall, xylan is also present in it.

### Function of the Cell Wall

The cell wall is an integral component of the plant cell and it performs many essential functions.

- The plant cell wall provides definite shape, strength, and rigidity
- It also provides protection against mechanical stress and physical shocks
- It helps to control cell expansion due to the intake of water
- It helps in preventing water loss from the cell
- It is responsible for transporting substances between and across the cell
- It acts as a barrier between the interior cellular components and the external environment

# Nucleus

**The cell nucleus is a membrane-bound structure that contains the cell's hereditary information and controls the cell's growth and reproduction.**

It is the command center of a eukaryotic cell and is commonly the most prominent organelle in a cell accounting for about 10 percent of the cell's volume.

In general, a eukaryotic cell has only one nucleus. However, some eukaryotic cells are enucleated cells (without a nucleus), for example, red blood cells (RBCs); whereas, some are multinucleate (consists of two or more nuclei), for example, slime **molds**.

The nucleus is separated from the rest of the cell or the **cytoplasm** by a nuclear membrane.

As the nucleus regulates the integrity of genes and gene expression, it is also referred to as the control center of a cell.

### Nucleus Structure

The structure of a nucleus encompasses the nuclear membrane, nucleoplasm, chromosomes, and nucleolus.

### Nuclear Membrane

- The nuclear membrane is a double-layered structure that encloses the contents of the nucleus. The outer layer of the membrane is connected to the endoplasmic reticulum.
- Like the cell membrane, the nuclear envelope consists of phospholipids that form a lipid bilayer.
- The envelope helps to maintain the shape of the nucleus and assists in regulating the flow of molecules into and out of the nucleus through nuclear pores. The nucleus communicates with the remaining of the cell or the cytoplasm through several openings called nuclear pores.
- Such nuclear pores are the sites for the exchange of large molecules (proteins and RNA) between the nucleus and cytoplasm.
- A fluid-filled space or perinuclear space is present between the two layers of a nuclear membrane.

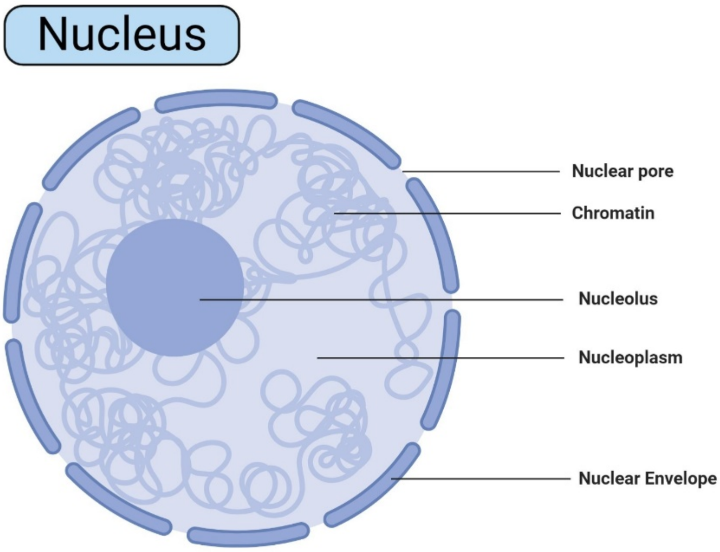



Figure: Nucleus, Image Copyright © Sagar Aryal, www.microbenotes.com

### Nucleoplasm

- Nucleoplasm is the gelatinous substance within the nuclear envelope.
- Also called karyoplasm, this semi-aqueous material is similar to the cytoplasm and is composed mainly of water with dissolved salts, enzymes, and organic molecules suspended within.
- The nucleolus and chromosomes are surrounded by nucleoplasm, which functions to cushion and protect the contents of the nucleus.
- Nucleoplasm also supports the nucleus by helping to maintain its shape. Additionally, nucleoplasm provides a medium by which materials, such as enzymes and nucleotides (DNA and RNA subunits), can be transported throughout the nucleus. Substances are exchanged between the cytoplasm and nucleoplasm through nuclear pores.
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## Nucleolus

- Contained within the nucleus is a dense, membrane-less structure composed of RNA and proteins called the nucleolus.
- Some of the eukaryotic organisms have a nucleus that contains up to four nucleoli.
- The nucleolus contains nucleolar organizers, which are parts of chromosomes with the genes for ribosome synthesis on them. The nucleolus helps to synthesize ribosomes by transcribing and assembling ribosomal RNA subunits. These subunits join together to form a ribosome during protein synthesis.
- The nucleolus disappears when a cell undergoes division and is reformed after the completion of cell division.

## Chromosomes

- The nucleus is the organelle that houses chromosomes.
- Chromosomes consist of DNA, which contains heredity information and instructions for cell growth, development, and reproduction.
- Chromosomes are present in the form of strings of DNA and histones (protein molecules) called chromatin.
- When a cell is "resting" i.e. not dividing, the chromosomes are organized into long entangled structures called chromatin.
- The chromatin is further classified into heterochromatin and euchromatin based on the functions. The former type is a highly condensed, transcriptionally inactive form, mostly present adjacent to the nuclear membrane. On the other hand, euchromatin is a delicate, less condensed organization of chromatin, which is found abundantly in a transcribing cell.

Besides the nucleolus, the nucleus contains a number of other non-membrane-delineated bodies. These include Cajal bodies, Gemini of coiled bodies, polymorphic interphase karyosome association (PIKA), promyelocytic leukemia (PML) bodies, paraspeckles, and splicing speckles.

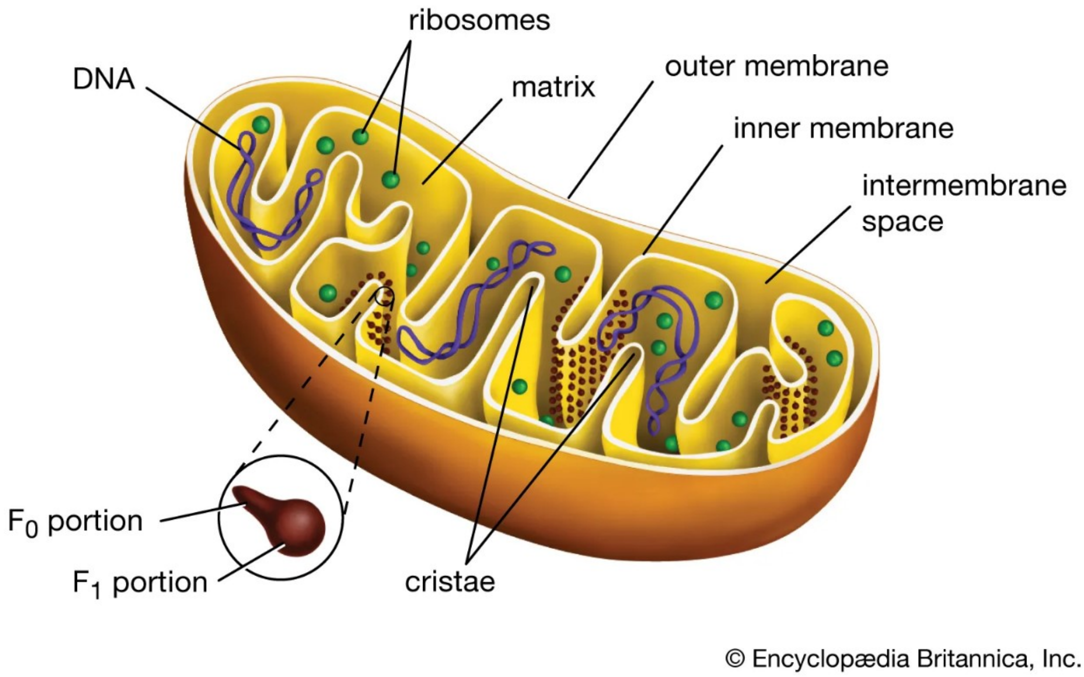
## Nucleus Functions

- It controls the hereditary characteristics of an organism.
- The organelle is also responsible for protein synthesis, cell division, growth, and differentiation.
- Storage of hereditary material, the genes in the form of long and thin DNA (deoxyribonucleic acid) strands, referred to as chromatin.
- Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
- The nucleus is a site for transcription in which messenger RNA (mRNA) are produced for protein synthesis.
- During the cell division, chromatins are arranged into chromosomes in the nucleus.
- Production of ribosomes (protein factories) in the nucleolus.
- Selective transportation of regulatory factors and energy molecules through nuclear pores.

# Utra Structure of Mitochondria

Mitochondria are mobile, plastic organelles that have a double-membrane structure. It ranges from 0.5 to 1.0 micrometer in diameter. It has four distinct domains: the outer membrane, the inner membrane, the intermembrane space, and the matrix.

- The organelle is enclosed by two membranes—a smooth outer membrane and a markedly folded or tubular inner mitochondrial membrane, which has a large surface and encloses the matrix space.
- The intermembrane space is located between the inner and outer membranes.
- The number and shape of the mitochondria, as well as the numbers of cristae they have, can differ widely from cell type to cell type.
- Tissues with intensive oxidative metabolism— e. g., heart muscle—have mitochondria with particularly large numbers of cristae.
- Even within one type of tissue, the shape of the mitochondria can vary depending on their functional status.
- Both mitochondrial membranes are very rich in proteins.

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Mitochondria consists of a mitochondrial membrane and a mitochondrial chamber.

### 1. Mitochondrial membrane

It consists of two membranes. They are:

#### a. Outer membrane

- It is a smooth membrane.
- It is made up of 40% **lipids** and 60% **proteins**.

- Due to the presence of the pores or porins, it is permeable.

### b. Inner membrane

- It is made up of 20% lipids and 80% proteins.
- It is the selectively permeable membrane.
- Since the membrane is folded inwards and there is the presence of cristae, it is said as the rough membrane.
- Cristae are the numerous and finger-like projections.
- Tennis racket-like particles are present in each crista.
- The particles were previously named as the inner membrane subunits, F0-F1 particles, elementary particles, or oxysomes.
- It was called the electron transport particles (ETP)by Parsons in 1963.
- In each mitochondrion about 104-105 particles are present.
- Base, stalk, and head are present in each elementary particle.
- Base and head are also called the F0 and F1 particles respectively.
- Stalk acts as the link which connects the base and head.
- The base is made up of hydrophobic proteins and is embedded in the lipid molecules of the membrane.
- The Head is made up of five types of the polypeptide.
- ATPase or ATP synthetase is the enzyme present in it.
- The ADP aids in the formation of ATP.
- Similarly, inorganic phosphate is also formed. It is due to oxidative phosphorylation.
- The stalk also consists of the coupling factors which connect the respiratory chain with the elementary particle.

## 2. Mitochondrial Chambers

Two chambers are present in the mitochondria i.e Outer and inner chamber.

### a. Outer chamber (peri-mitochondrion space)

- Between the outer and the inner mitochondrial membrane, a space is present in between them which is known as the peri-mitochondrion space.
- Few enzymes are also present in the fluid present in it.

### b. Inner chamber

- It is present in the inner part of the inner membrane.
- A semi-fluid matrix is present in it which consists of:
    - Water

- Minerals
- Protein particles
- 70s ribosomes
- RNA
- Circular DNA
- Enzymes

### Mitochondrial Matrix

- The mitochondrial matrix which is the liquid (colloidal) area encircled by the inner membrane, contains the soluble enzymes of the **Krebs cycle** which completely oxidize the acetyl-CoA to produce CO2, H2O and hydrogen ions. Hydrogen ions reduce the molecules of NAD and FAD, both of which pass on hydrogen ions to respiratory or electron transport chain where oxidative phosphorylation takes place to generate energy-rich ATP molecules.
- Mitochondria also contain in their matrix single or double circular and double-stranded DNA molecules called mt DNA and also the 55S ribosomes, called mitoribosomes. Since mitochondria can synthesize 10 percent of their proteins in their own protein-synthetic machinery, they are considered as **semi-autonomous organelles**.

### Functions of Mitochondria

- Mitochondria stores and releases energy in the form of ATP ( Adenosine triphosphate ). It occurs by the oxidation of carbohydrates, proteins, and fats. It will be further utilized in the different metabolic activities. So, mitochondria are known as the **powerhouse of the cell** or storage batteries of the cell.
- Mitochondria help in the formation of the heme of hemoglobin.
- During cellular respiration, mitochondria form the different intermediate products. They are utilized for the synthesis of cytochromes, chlorophyll, ferredoxin, steroids, alkaloids, pyrimidines, etc.
- Calcium can be stored and released by the mitochondria.
- It helps in the formation of amino acids.
- In the matrix of the mitochondria, several fatty acids can be synthesized.
- During the process of oogenesis, they help in the formation of the yolk.
- During the process of spermatogenesis, they help in the formation of the middle part of the sperms.
- By the process of maternal inheritance, traits are directly transferred by mitochondria from the mothers to the offsprings.
- Mitochondria are also present in the liver cell. They help in the detoxification of ammonia using their enzymes.
- Mitochondria are the site of heat generation which is known as thermogenesis.

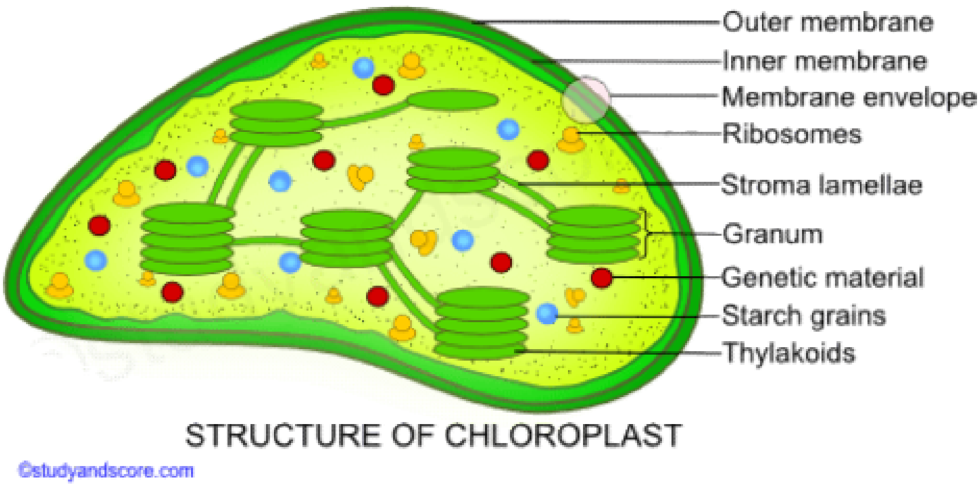
- Sometimes there can be the abnormal death of the cell. It might be due to the dysfunctioning of the mitochondria. It can affect the function of the organ.
- It helps in the formation of some parts of the hormone of testosterone and estrogen.

## Ultra Structure of Chloroplast

- Chloroplasts found in higher plants are generally biconvex or planoconvex shaped.
- In different plants, however, chloroplasts may have different shapes, varying from spheroid, filamentous saucer-shaped, discoid or ovoid-shaped.
- They can be found in the cells of the mesophyll in plant leaves. They are vesicular and have a colorless center.
- The average size of the chloroplast is 4-6 Âµ in diameter and 1-3 Âµ in thickness.

The chloroplast has an inner and outer membrane with an empty intermediate space in between. Inside the chloroplast are stacks of thylakoids, called grana, as well as stroma, the dense fluid inside of the chloroplast. These thylakoids contain the chlorophyll that is necessary for the plant to go through photosynthesis. The space the chlorophyll fills is called the thylakoid space.

**A chloroplast thus has the following parts:**




1. **Envelope (Outer membrane)**

It is a semi-porous membrane and is permeable to small molecules and ions, which diffuses easily. The outer membrane is not permeable to larger proteins.

2. **Intermembrane Space**

It is usually a thin inter-membrane space about 10-20 nanometers and it is present between the outer and the inner membrane of the chloroplast.

3. **Inner membrane**

The inner membrane of the chloroplast forms a border to the stroma. It regulates the passage of materials in and out of the chloroplast. In addition to regulation activity, fatty acids, lipids, and carotenoids are synthesized in the inner chloroplast membrane.

4. **Stroma**

Stroma is an alkaline, aqueous fluid that is protein-rich and is present within the inner membrane of the chloroplast. The space outside the thylakoid space is called the stroma. The chloroplast DNA chloroplast ribosomes and the thylakoid system, starch granules and many proteins are found floating around the stroma.

5. **Thylakoid System**

The thylakoid system is suspended in the stroma. The thylakoid system is a collection of membranous sacs called thylakoids. The chlorophyll is found in the thylakoids and is the sight for the process of light reactions of photosynthesis to happen. The thylakoids are arranged in stacks known as grana. Each granum contains around 10-20 thylakoids.

**Peripheral Reticulum**

The chloroplasts of certain plants contain an additional set of membranous tubules called peripheral reticulum that originates from the inner membrane of the envelope. Tiny vesicles bud off from the inner membrane of the chloroplast and assemble to form the tubules of the peripheral reticulum.

**Semi-autonomous nature of chloroplast**

- Like the mitochondria, they are also known as semi-autonomous cell organelles as they have their DNA and complete machinery to synthesize some of the required proteins.
- While some other proteins depend upon nuclear DNA and cytoplasmic ribosomes.
- Chloroplast and mitochondria are the only two organelles having their DNA.
- **Types of Pigments**
- **Chlorophyll**
- Chlorophyll is a green pigment located within the chloroplast. More specifically, it is found in the thylakoid membranes.
- The chlorophyll consists of 75% of chlorophyll a and 25% of chlorophyll b.
- The chlorophyll absorbs energy from sunlight and the synthesis of food molecules in the chloroplast.
- **Carotenoids**
- Carotenoids are the pigments present in chlorophylls which are located in the thylakoid membrane. Pigments like yellow and orange are present in it.
- Carotenoids are related to vitamin A.
- They are important because they can absorb a certain wavelength of light that can not be absorbed by chlorophylls.
- Carotenoids are involved in a function known as photoprotection.
- **Xanthophylls**
- The carotenoids are carotenes and xanthophylls. Xanthophylls are present in the brown and green algae.

- **Phycobilin**
- Phycobilin is found only in red algae and *Cyanobacteria.* It has a relatively narrow distribution.
- Phycoerythrin and phycocyanin are other accessory pigments belonging to this family.
- Phycoerythrin makes red algae commonly red and phycocyanin causes the *Cyanobacteria* to appear blue-green.

### Functions of Chloroplasts

Chloroplasts are the sites for photosynthesis, which comprises a set of light-dependent and light-independent reactions to harness solar energy and convert it into chemical energy.

The components of chloroplast participate in several regulatory functions of the cell as well as in photorespiration.

Chloroplasts also provide diverse metabolic activities for plant cells, including the synthesis of fatty acids, membrane lipids, isoprenoids, tetrapyrroles, starch, and hormones.

The chloroplasts with the nucleus and cell membrane and ER are the key organelles of pathogen defense.

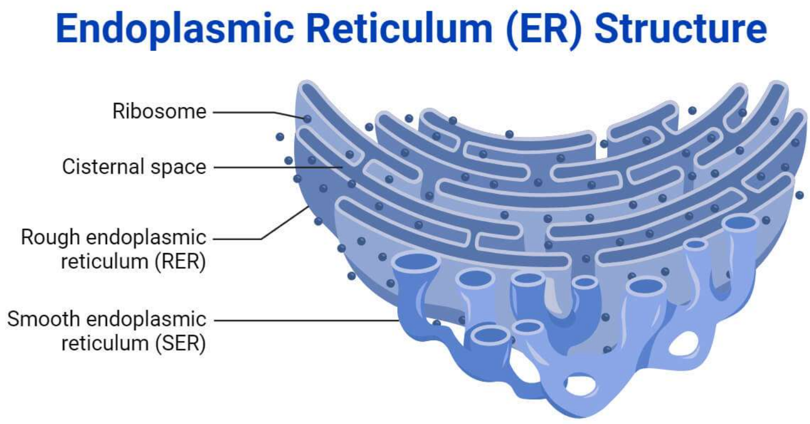
Chloroplasts can serve as cellular sensors.

# Endoplasmic Reticulum (ER)

within the cytoplasm of most animal cells is an extensive network (reticulum) of membrane-limited channels, collectively called the endoplasmic reticulum (or ER).

### structure of Endoplasmic Reticulum (ER)

- The membrane of the endoplasmic reticulum is 50 to 60 Aº thickness and **fluid-mosaic** like the unit membrane of the plasma membrane.
- The membranes of the endoplasmic reticulum are found to contain many kinds of enzymes that are needed for various important synthetic activities. The most important enzymes are the stearases, NADH-cytochrome C reductase, NADH diaphorase, glucose-6-phosphatase, and Mg++ activated ATPase.
- The membrane of endoplasmic reticulum remains continuous with the membranes of the plasma membrane, nuclear membrane, and Golgi apparatus.
- The cavity of the endoplasmic reticulum is well developed and acts as a passage for the secretory products.




The endoplasmic reticulum may occur in the following three forms:

1. Lamellar form or cisternae
2. Vesicular form or vesicle and
3. Tubular form or tubules.

### The Cisternae

- RER usually exists as cisternae that occur in those cells which have synthetic roles as the cells of the pancreas, notochord, and brain.
- The cisternae are long, flattened, sac-like, unbranched tubules having a diameter of 40 to 50 µm.
- They remain arranged parallelly in bundles or stakes.

### The Vesicles

- The vesicles are oval; membrane-bound vacuolar structures having a diameter of 25 to 500 µm.
- They often remain isolated in the cytoplasm and occur in most cells but especially abundant in the SER.

### The Tubules

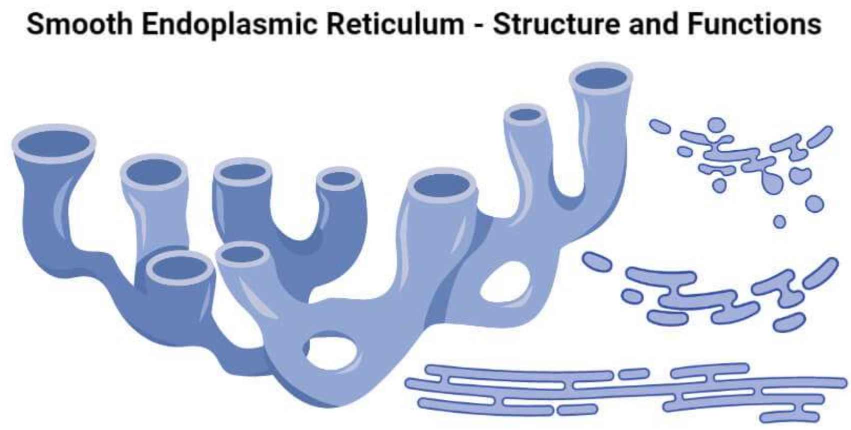
- The tubules are branched structures forming the reticular system along with the cisternae and vesicles.
- They usually have a diameter from 50 to 190 µm and occur almost in all the cells.
- Tubular form of ER is often found in SER and is dynamic in nature, i.e., it is associated with membrane movements, fission and fusion between membranes of cytocavity network.

### Types of Endoplasmic Reticulum (ER)

**1. Smooth Endoplasmic Reticulum**

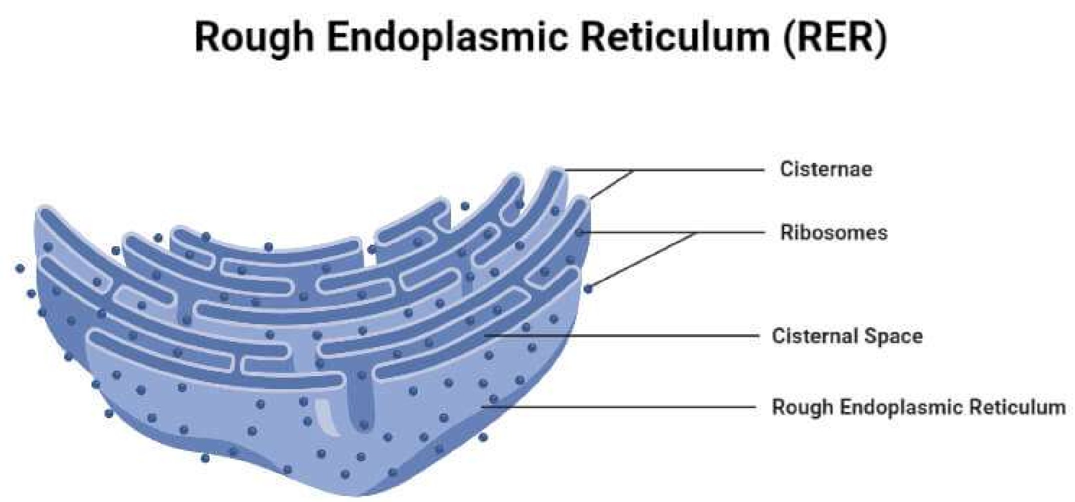
- They are also called as the agranular endoplasmic reticulum.

- This type of endoplasmic reticulum possesses smooth walls because the ribosomes are not attached to its membranes.
- The smooth type of endoplasmic reticulum occurs mostly in those cells, which are involved in the metabolism of lipids (including steroids) and glycogen. Eg. adipose cells, interstitial cells, glycogen storing cells of the liver, conduction fibers of heart, spermatocytes, and leucocytes.




## 2. Rough Endoplasmic Reticulum

- It possesses rough walls because the ribosomes remain attached to its membranes.
- On their membranes, rough ER (RER) contains certain ribosome specific, transmembrane glycoproteins, called ribophorins I and II, to which are attached the ribosomes while engaged in polypeptide synthesis.
- The rough type of endoplasmic reticulum is found abundantly in those cells which are active in protein syntheses such as pancreatic cells, plasma cells, goblet cells, and liver cells.




## Functions of Endoplasmic Reticulum (ER)

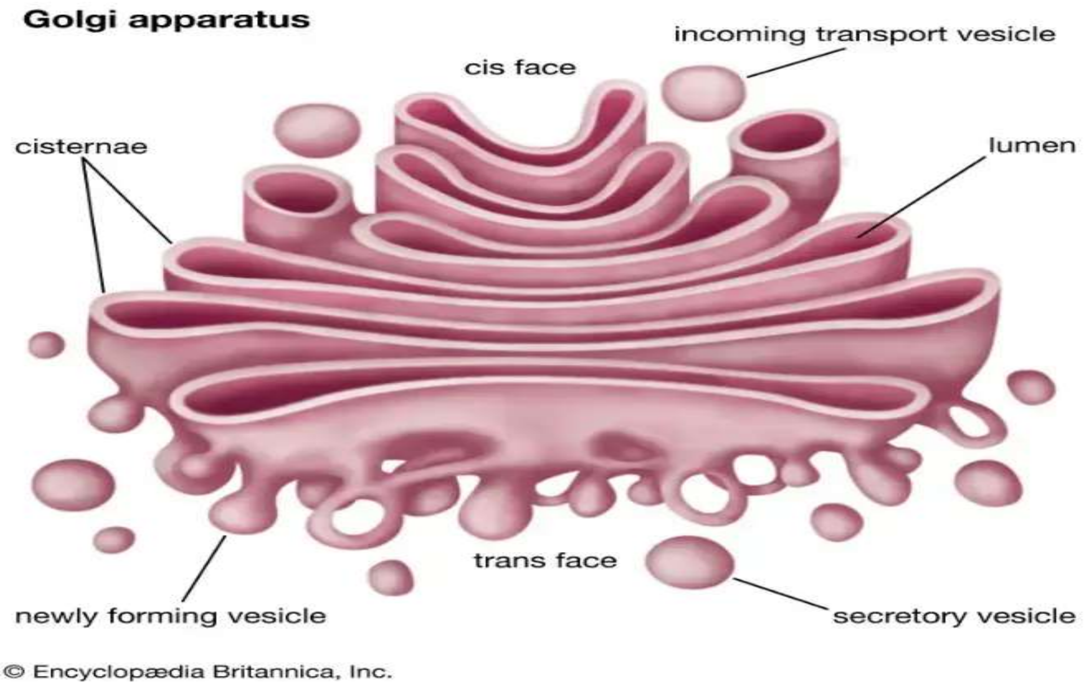
- Functions of smooth ER include lipid metabolism (both catabolism and anabolism; they synthesize a variety of phospholipids, cholesterol, and steroids).

- Glycogenolysis (degradation of glycogen; glycogen being polymerized in the cytosol).
- Drug detoxification (by the help of the cytochrome P-450).
- The endoplasmic reticulum provides an ultrastructural skeletal framework to the cell and gives mechanical support to the colloidal cytoplasmic matrix.
- The exchange of molecules by the process of osmosis, diffusion and active transport occurs through the membranes of the endoplasmic reticulum.
- The endoplasmic reticulum is the main component of the endomembrane system, also called the cytoplasmic vacuolar system or cytocavity network.
- The endoplasmic membranes contain many enzymes that perform various synthetic and metabolic activities. Further, the endoplasmic reticulum provides an increased surface for various enzymatic reactions.
- The endoplasmic reticulum acts as an intracellular circulatory or transporting system.
- RER pinches off certain tiny protein-filled vesicles which ultimately get fused to cis Golgi.
- The ER membranes form the new nuclear envelope after each nuclear division.
- The SER contains several key enzymes that catalyze the synthesis of cholesterol which is also a precursor substance for the biosynthesis of two types of compounds— the steroid hormones and bile acids.

# Golgi complex

- The Golgi apparatus or the Golgi body or Golgi complex or simply Golgi is a cellular organelle present in most of the cells of the eukaryotic organisms.
- It is referred to as the manufacturing and the shipping center of the cell.
- Golgi is involved in the packaging of the protein molecules before they are sent to their destination. These organelles help in processing and packaging the macromolecules like **proteins** and lipids that are synthesized by the cell and hence act as the 'post office' of the cell.
- Golgi apparatus was discovered in the year 1898 by an Italian biologist Camillo Golgi.

## Structure of Golgi Apparatus




- Under the electron microscope, the Golgi apparatus is seen to be composed of stacks of flattened structures that contain numerous vesicles containing secretory granules.
- The Golgi apparatus is morphologically very similar in both plant and animal cells. However, it is extremely pleomorphic: in some cell types it appears compact and limited, in others spread out and reticular (net-like).
- Typically, however, Golgi apparatus appears as a complex array of **interconnecting tubules, vesicles, and cisternae.**

### A. Cisternae

- It is the simplest unit of the Golgi apparatus is the cisterna.
- Cisternae (about 1 µm in diameter) are central, flattened, plate-like or saucer-like closed compartments that are held in parallel bundles or stacks one above the other.
- In each stack, cisternae are separated by a space of 20 to 30 nm which may contain rod-like elements or fibers.
- Each stack of cisternae forms a dictyosome which may contain 5 to 6 Golgi cisternae in animal cells or 20 or more cisternae in plant cells.
- Each cisterna is bounded by a smooth unit membrane (7.5 nm thick), having a lumen varying in width from about 500 to 1000 nm.

- The margins of each cisterna are gently curved so that the entire dictyosome of the Golgi apparatus takes on a bow-like appearance.
- The cisternae at the convex end of the dictyosome comprise proximal, forming or cis-face and cisternae at the concave end of the dictyosome comprise the distal, maturing or trans-face.

### B. Tubules

- A complex array of associated vesicles and anastomosing tubules (30 to 50 nm diameter) surround the dictyosome and radiate from it. In fact, the peripheral area of the dictyosome is fenestrated (lace-like) in structure.

### C. Vesicles

The vesicles (60 nm in diameter) are of three types:

**(i) Transitional vesicles** are small membrane limited vesicles which are thought to form as blebs from the transitional ER to migrate and converge to cis face of Golgi, where they coalesce to form new cisternae.

**(ii) Secretory vesicles** are varied-sized membrane-limited vesicles that discharge from margins of cisternae of Golgi. They, often, occur between the maturing face of Golgi and the plasma membrane.

**(iii) Clathrin-coated vesicles** are spherical protuberances, about 50 µm in diameter and with a rough surface. They are found at the periphery of the organelle, usually at the ends of single tubules, and are morphologically quite distinct from the secretory vesicles. The clathrin-coated vesicles are known to play a role in intracellular traffic of membranes and of secretory products, i.e., between ER and Golgi, as well as, between the GELR region and the endosomal and lysosomal compartments.

## Functions of Golgi Apparatus

. Golgi vesicles are often, referred to **as the "traffic police" of the cell**. They play a key role in sorting many of the cell's proteins and membrane constituents, and in directing them to their proper destinations.

- To perform this function, the Golgi vesicles contain different sets of enzymes in different types of vesicles— cis, middle and trans cisternae—that react with and modify secretory proteins passing through the Golgi lumen or membrane proteins and glycoproteins that are transiently in the Golgi membranes as they are en route to their final destinations.
- The Golgi apparatus hence acts as the assembly factory of the cell where the raw materials are directed to the Golgi apparatus before being passed out from the cell.

. In animals, the Golgi apparatus is involved in the packaging and exocytosis

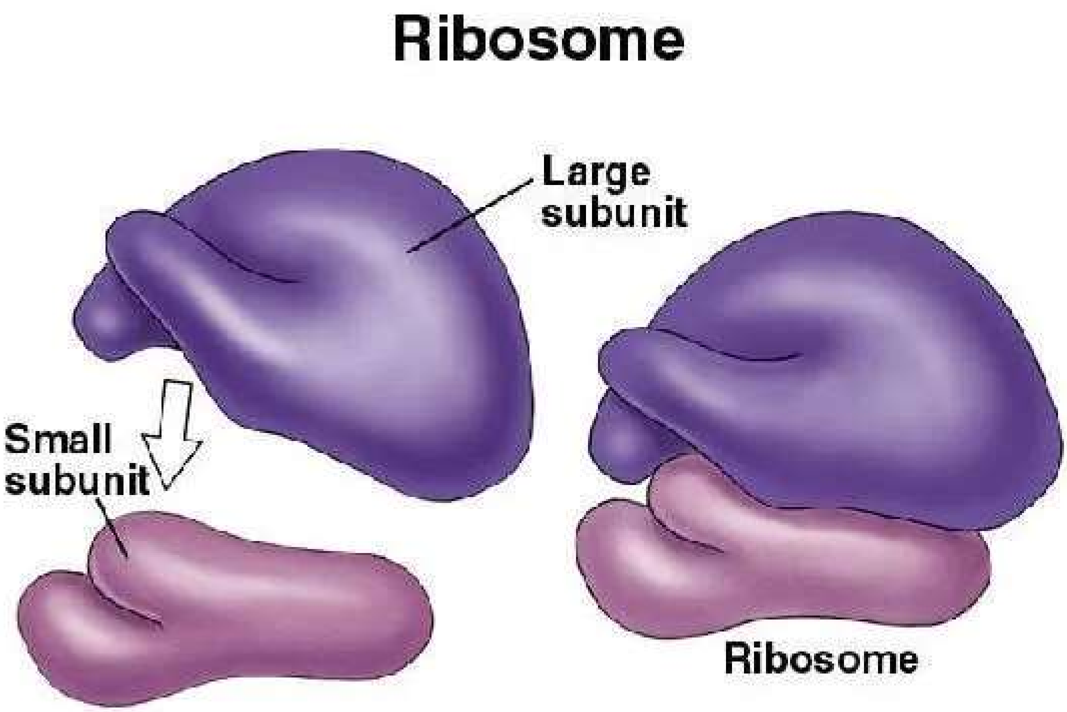
. It is also involved in the formation of certain cellular organelles such as plasma membrane, lysosomes, acrosome of spermatozoa and cortical granules of a variety of oocytes.

. They are also involved in the transport of lipid molecules around the cell.

# Ribosomes

Ribosomes are non-membrane-bound cellular structures that act as the cell's "protein factories" by translating genetic instructions from messenger RNA (mRNA) into polypeptide chains. They are found in all living cells, including prokaryotes and eukaryotes.

## Structure and composition




- Ribosomes are composed of ribosomal RNA (rRNA) and many different proteins, forming a ribonucleoprotein complex.
- Each ribosome has two subunits: a large subunit and a small subunit, which only assemble during protein synthesis.
- The small subunit is responsible for binding to the mRNA and decoding its genetic message.
- The large subunit joins amino acids together to form the growing protein chain.
- The interface between the subunits contains the binding sites for mRNA and transfer RNA (tRNA) molecules.

## Types of ribosomes

| Characteristic | Prokaryotic (70S) ribosomes | Eukaryotic (80S) ribosomes |
|---|---|---|
| Size | Smaller (70S, with 50S and 30S subunits) | Larger (80S, with 60S and 40S subunits) |
| Location | Free-floating in the cytoplasm | Found in the cytoplasm (free or bound to the endoplasmic reticulum), mitochondria, and chloroplasts |
| Composition | Roughly 65% rRNA and 35% protein | Approximately 45% rRNA and 55% protein |
| rRNA molecules | Three types: 16S (in 30S), 23S, and 5S (in 50S) | Four types: 18S (in 40S), 28S, 5.8S, and 5S (in 60S) |

*Note: The "S" in ribosome types refers to the Svedberg unit, a measure of sedimentation rate, not size, which is why the subunits don't add up arithmetically.*

Location and protein destination

The final destination of a protein depends on whether the ribosome is free-floating in the cytoplasm or bound to the endoplasmic reticulum (ER).

- Free ribosomes float in the cytosol and produce proteins that will be used within the cell.
- Bound ribosomes attach to the rough endoplasmic reticulum (RER) and synthesize proteins destined for secretion outside the cell, insertion into a membrane, or delivery to specific organelles.

## Functions of Ribosomes

The ribosome is a complex molecular machine, found within all living cells, that serves as the site of biological protein synthesis (translation).

Ribosomes link amino acids together in the order specified by messenger RNA (mRNA) molecules.

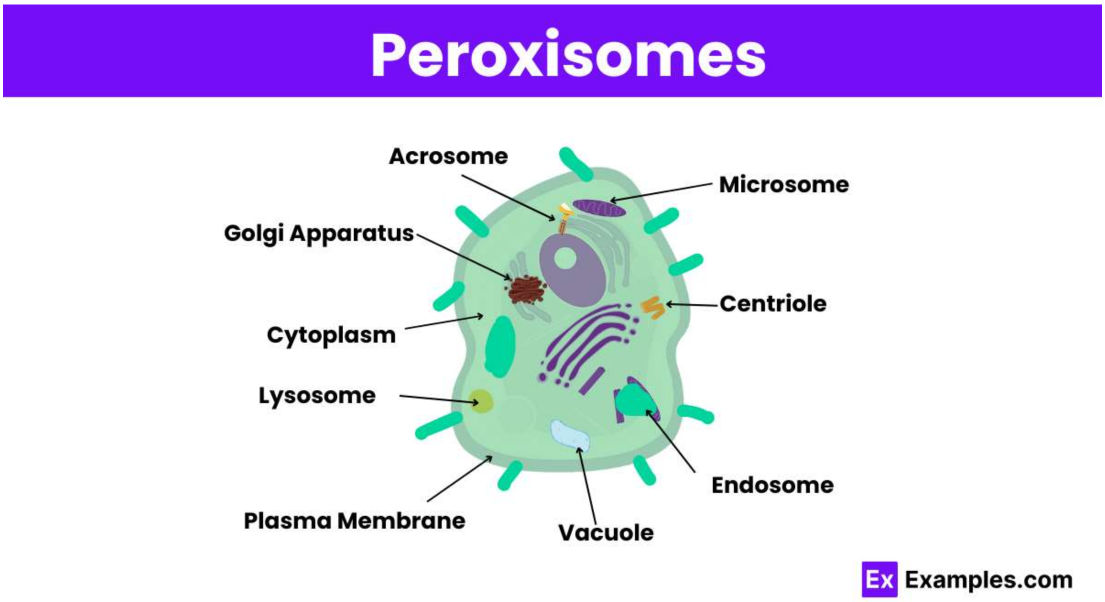
Ribosomes act as catalysts in two extremely important biological processes called peptidyl transfer and peptidyl hydrolysis.

The nascent polypeptide chain is protected from the activity of protein digestive enzymes.

# Peroxisomes

Peroxisomes are single-membrane-bound organelles in eukaryotic cells vital for metabolic and detoxification processes, especially lipid metabolism and the management of hydrogen peroxide ($H_2O_2$). Key functions include fatty acid breakdown (beta-oxidation), detoxification of harmful substances, synthesis of plasmalogens (essential phospholipids for myelin), and photorespiration in plants. They replicate by division, not from their own DNA, and contain oxidative enzymes like catalase to break down $H_2O_2$ into water and oxygen.

## Structure




- **Single Membrane:** Enclosed by a single lipid bilayer membrane.
- **Granular Matrix:** Contains a dense concentration of metabolic enzymes and proteins, sometimes forming a crystalline core.
- **No Genetic Material:** Lacks its own DNA or ribosomes, unlike mitochondria and chloroplasts.

## Functions

- **Lipid Metabolism:** Breaks down very-long-chain fatty acids through the beta-oxidation pathway.
- **Detoxification:** Neutralizes harmful substances and detoxifies alcohol by producing and immediately breaking down hydrogen peroxide into water and oxygen via enzymes like catalase.
- **Biosynthesis:** Synthesizes plasmalogens, vital phospholipids found in nerve cell myelin.
- **Photorespiration:** In plants, peroxisomes are crucial for the process of photorespiration.
- **Other Processes:** Involved in the catabolism of D-amino acids, polyamines, and bile acids, as well as the oxidation of urate in some animals.

# Glyoxysomes

Glyoxysomes are specialized peroxisomes—membrane-bound organelles found in the fat-storage tissues of germinating seeds and in filamentous fungi. Discovered by Harry Beevers and Breidenbach in 1961, these organelles are temporary, appearing during germination to convert stored fatty acids into carbohydrates.

Function and metabolism

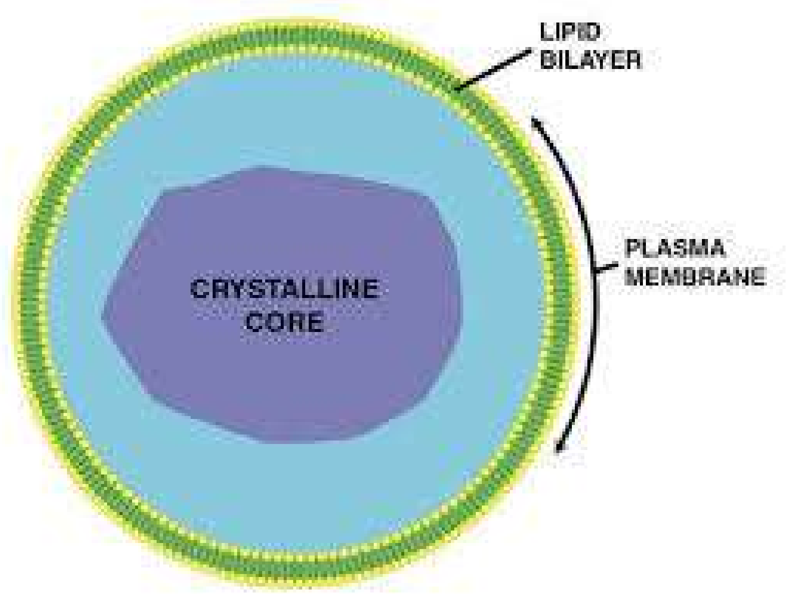
The primary role of glyoxysomes is to facilitate the conversion of stored fatty acids into sugars, a process essential for a growing seedling before it can perform photosynthesis. This is accomplished through two key metabolic processes:

- Beta-oxidation: This process breaks down fatty acids into two-carbon units of acetyl-CoA.
- The glyoxylate cycle: This modified version of the Krebs cycle utilizes the acetyl-CoA from beta-oxidation to produce succinate, bypassing the decarboxylation steps of the standard Krebs cycle. Succinate is then converted into carbohydrates via gluconeogenesis, providing the seedling with the energy it needs to grow.

Key enzymes: Glyoxysomes contain all the enzymes necessary for both beta-oxidation and the glyoxylate cycle, including the following key enzymes:

- Isocitrate lyase
- Malate synthase
- Citrate synthase
- Aconitase
- Catalase (to break down the hydrogen peroxide produced during beta-oxidation)

## Structure and location



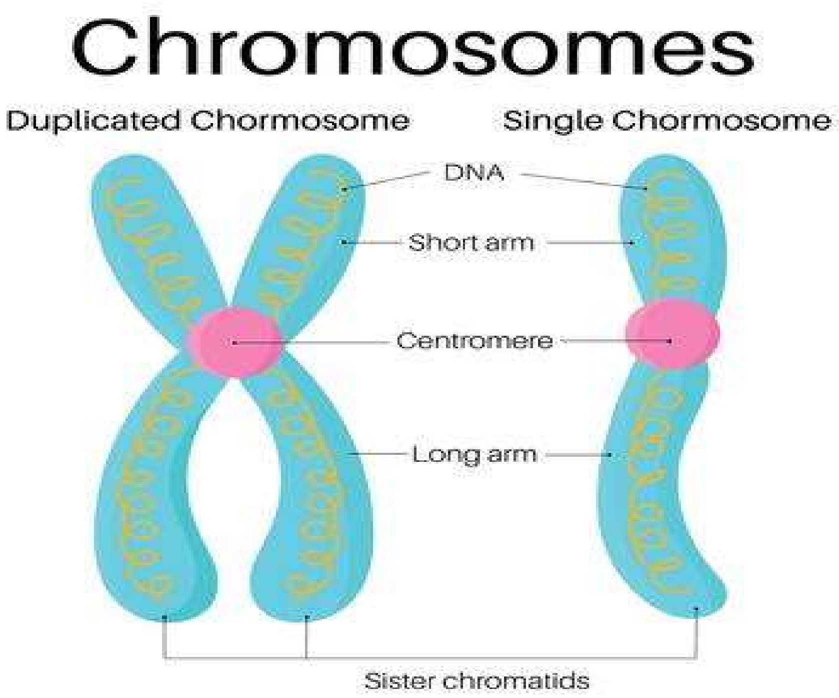
- Structure: A glyoxysome is a single-membrane-bound organelle with a finely granular matrix, which may contain a dense crystalline core of enzymes.
- Size: They are typically spherical or ovoid and measure about 0.1 to 1 micrometer in diameter.
- Location: They are prominent in the fat-rich storage tissues, such as the endosperm or cotyledons, of germinating oilseeds. Common examples include castor beans, peanuts, sunflowers, and pumpkins.

allowing them to convert fat into carbohydrates—a function that is unique to glyoxysomes and does not occur in typical peroxisomes or in most animal cells.

# Structure of Chromosomes

In the nucleus of each cell, the **DNA** molecule is packaged into thread-like structures called chromosomes. Each chromosome is made up of DNA tightly coiled many times around proteins called histones that support its structure. Chromosomes were first described by Strasburger (1815), and the term ‘chromosome’ was first used by Waldeyer in 1888. They appear as rod-shaped dark stained bodies during the metaphase stage of mitosis when cells are stained with a suitable basic dye and viewed under a light microscope.

## Chromosome Structure



## Main parts of chromosomes are:

- **Chromatid:** Each chromosome has two symmetrical structures called chromatids or sister chromatids which is visible in mitotic metaphase.
    - Each chromatid contains a single DNA molecule
    - At the anaphase of mitotic cell division, sister chromatids separate and migrate to opposite poles
- **Centromere and kinetochore:** Sister chromatids are joined by the centromere.
    - Spindle fibres during cell division are attached at the centromere
    - The number and position of the centromere differs in different chromosomes
    - The centromere is called primary constriction
    - Centromere divides the chromosome into two parts, the shorter arm is known as ‘p’ arm and the longer arm is known as ‘q’ arm.
    - The centromere contains a disc-shaped kinetochore, which has specific DNA sequence with special proteins bound to them
    - The kinetochore provides the centre for polymerisation of tubulin proteins and assembly of microtubules
- **Secondary constriction and nucleolar organisers:** Other than centromere, chromosomes possess secondary constrictions.
    - Secondary constrictions can be identified from centromere at anaphase because there is bending only at the centromere (primary constriction)
    - Secondary constrictions, which contain genes to form nucleoli are known as the nucleolar organiser
- **Telomere:** Terminal part of a chromosome is known as a telomere.
    - Telomeres are polar, which prevents the fusion of chromosomal segments
- **Satellite:** It is an elongated segment that is sometimes present on a chromosome at the secondary constriction.
    - The chromosomes with satellite are known as sat-chromosome
- **Chromatin:** Chromosome is made up of chromatin. Chromatin is made up of DNA, RNA and proteins. At interphase, chromosomes are visible as thin chromatin fibres present in the nucleoplasm. During cell division, the chromatin fibres condense and chromosomes are visible with distinct features.
    - The darkly stained, condensed region of chromatin is known as heterochromatin. It contains tightly packed DNA, which is genetically inactive
    - The light stained, diffused region of chromatin is known as euchromatin. It contains genetically active and loosely packed DNA

- **At prophase, the chromosomal material is visible as thin filaments known as chromonemata**
- **At interphase, bead-like structures are visible, which are an accumulation of chromatin material called chromomere. Chromatin with chromomere looks like a necklace with beads**

## Types of Chromosomes

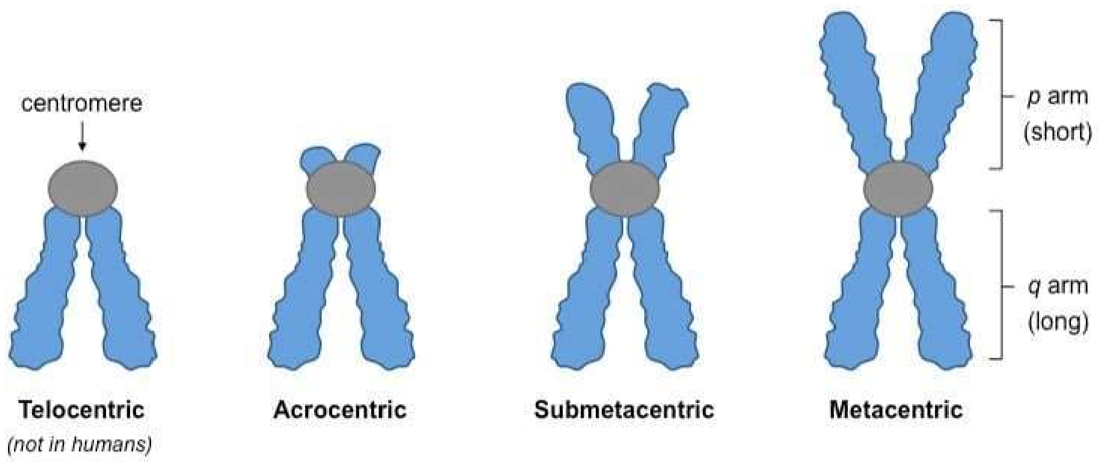
### A. Autosomes and Sex Chromosomes

- Human chromosomes are of two types- autosomes and sex chromosomes.
- Genetic traits that are linked to the sex of the person are passed on through the sex chromosomes. The rest of the genetic information is present in the autosomes.
- Humans have 23 pairs of chromosomes in their cells, of which 22 pairs are autosomes and one pair of sex chromosomes, making a total of 46 chromosomes in each cell.

### B. On the Basis of Number of Centromeres

- **Monocentric** with one centromere.
- **Dicentric** with two centromeres.
- **Polycentric** with more than two centromeres
- **Acentric** without centromere. Such chromosomes represent freshly broken segments of chromosomes which do not survive for long.
- **Diffused or non-located** with indistinct centromere diffused throughout the length of chromosome.

### C. On the Basis of Location of Centromere




- **Telocentric** are rod-shaped chromosomes with centromere occupying the terminal position, so that the chromosome has just one arm.
- **Acrocentric** are also rod-shaped chromosomes with centromere occupying a sub-terminal position. One arm is very long and the other is very short.

- **Sub-metacentric** chromosomes are with centromere slightly away from the mid-point so that the two arms are unequal.
- **Metacentric** are V-shaped chromosomes in which centromere lies in the middle of chromosome so that the two arms are almost equal.

# Functions of Chromosomes

- The main function of chromosomes is to carry the genetic material from one generation to another
- Chromosomes play an important role and act as a guiding force in the growth, reproduction, repair and regeneration process, which is important for their survival
- Chromosomes protect the DNA from getting tangled and damaged
- Histone and non-histone proteins help in the regulation of gene expression
- Spindle fibres attached to the centromere help in the movement of the chromosome during cell division
- Each chromosome contains thousands of genes that precisely code for multiple proteins present in the body

## Specialized chromosomes

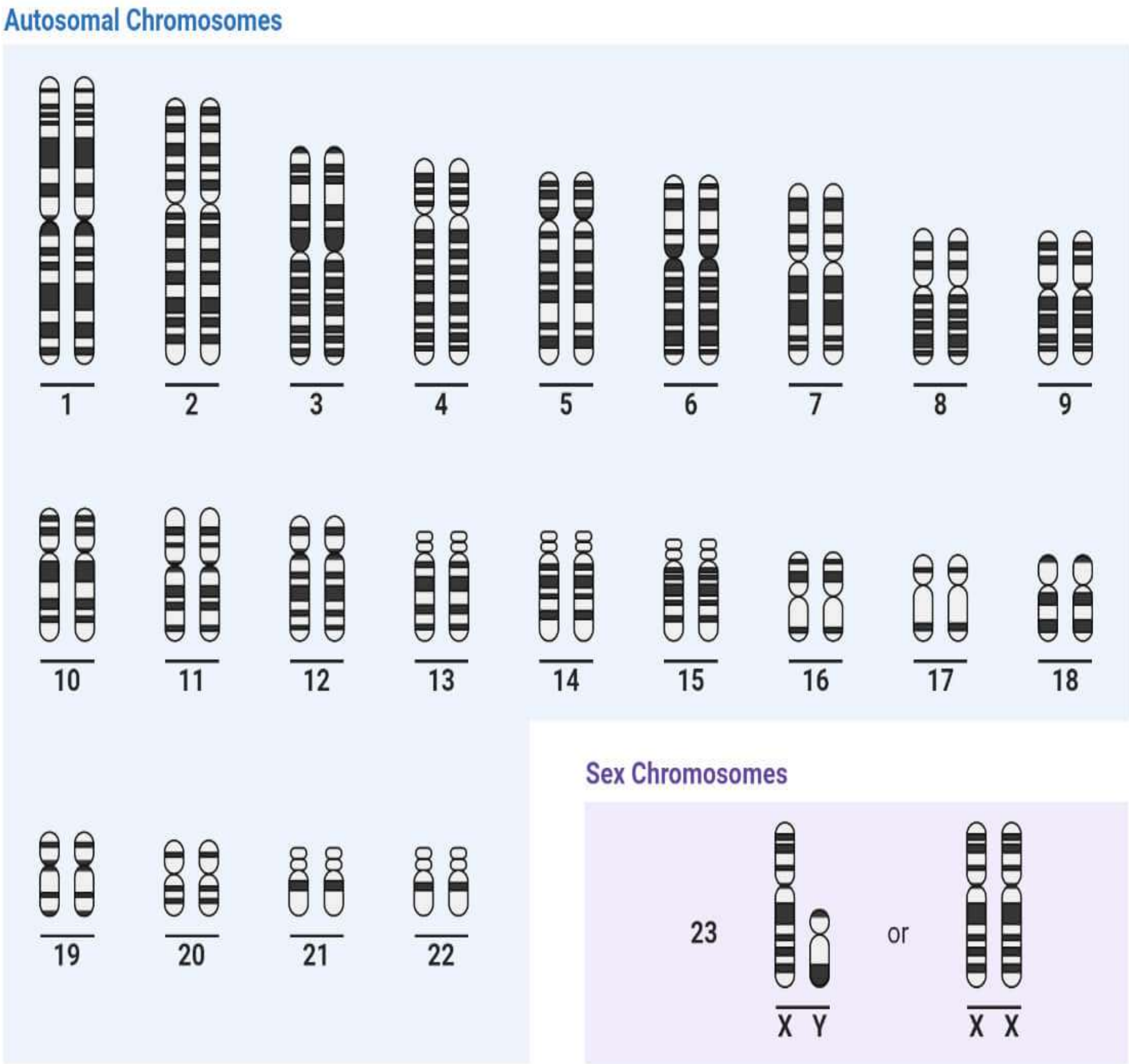



Figure: Human Karyotype.

**B. On the Basis of Number of Centromeres**

1. **Monocentric** with one centromere.
2. **Dicentric** with two centromeres.
3. **Polycentric** with more than two centromeres
4. **Acentric** without centromere. Such chromosomes represent freshly broken segments of chromosomes which do not survive for long.
5. **Diffused or non-located** with indistinct centromere diffused throughout the length of chromosome.

**C. On the Basis of Location of Centromere**

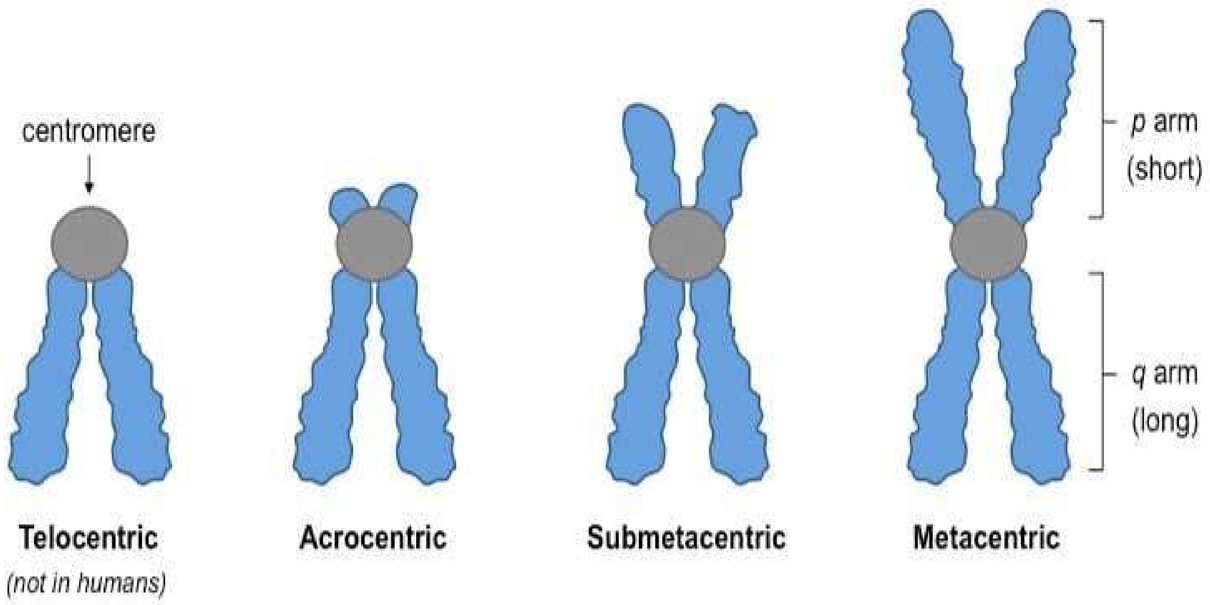



Figure: Types of Chromosomes. Image Source: BioNinja.

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## Special chromosomes / specialized chromosomes

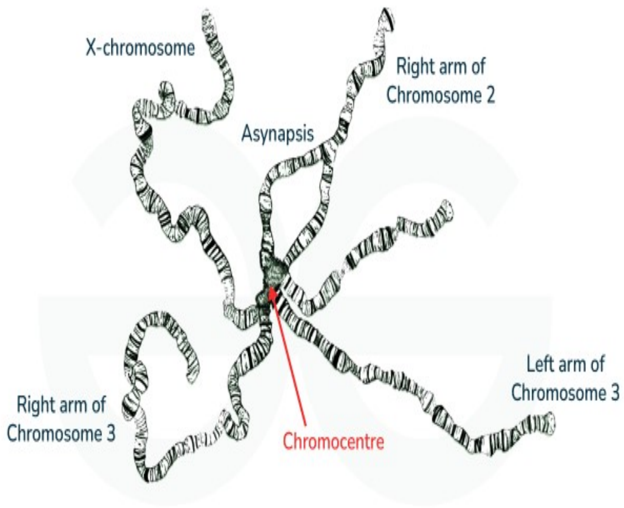
**Introduction:**

Special chromosomes are morphologically or functionally distinct from normal chromosomes, found in specific tissues or life stages, and include lampbrush chromosomes, characterized by large loops for gene transcription in growing oocytes; polytene chromosomes (giant chromosomes), formed by DNA replication without division in salivary glands for high-level RNA synthesis; and B-chromosomes, extra, non-essential chromosomes present in some populations that may lack essential genes and centromeres.

**types**

- Polytene chromosomes
- Lampbrush chromosome

## Polytene chromosomes:



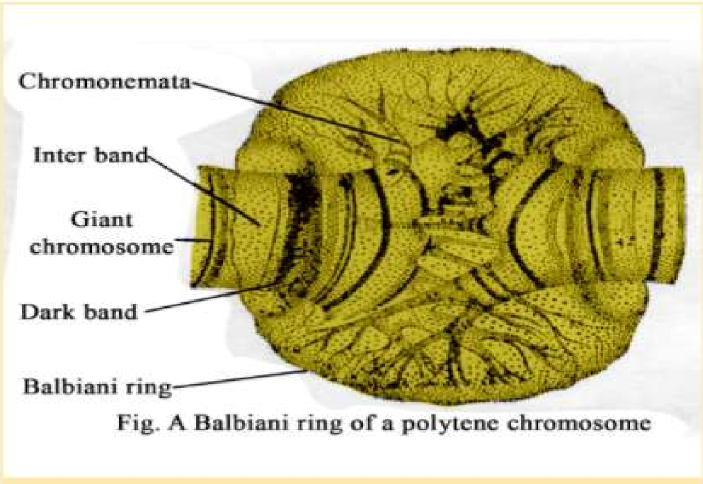



Fig. A Balbiani ring of a polytene chromosome

**Introduction:**

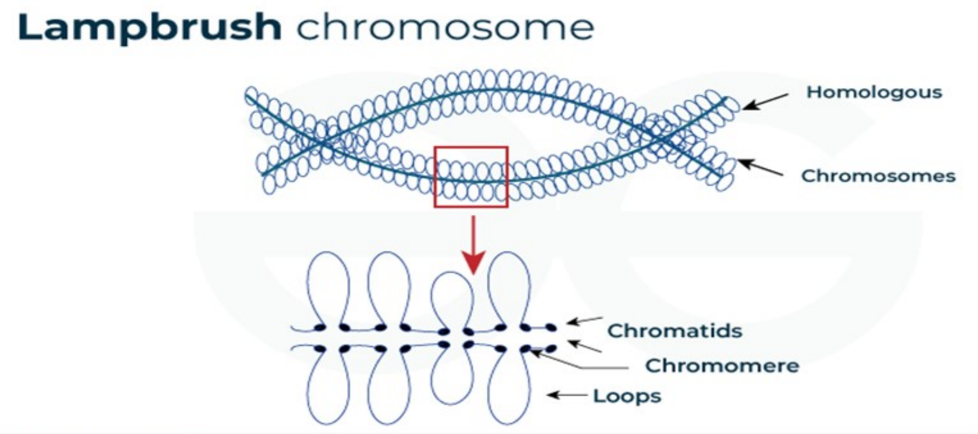
- This special type of chromosome is observed by Balbiani in salivary glands of the Chironomus larvae of Dipteran insects.
- Since they were discovered in the salivary glands, they were also called salivary gland chromosomes.
- The present name polytene chromosome was suggested by Kollar due to the occurrence of many chromonemata(DNA) in them.
- Thus, some cells of Drosophila, Chironomus and mosquitoes become very large having high DNA content.

- Polyteny of giant chromosomes is achieved by replication of the DNA several times without nuclear division and the resulting daughter chromatids do not separate but remain aligned side by side.

**Detailed explanation:**

- Chromonema is required to form Polytene chromosomes which are formed by chromosomal replication without nuclear division.
- The giant chromosomes are also formed by the process of somatic pairing between homologous chromosomes.
- The resultant daughter chromosomes remain aligned with each other and not separated from each other.
- This is very useful for the analysis of many facets of eukaryotic interphase chromosome organization and the genome as a whole.
- The salivary gland cells do not undergo mitosis and die during metamorphosis.
- This chromosome is symbolized by Balbiani rings or puffs which are swollen or puffy areas in polytene chromosomes.
- This chromosome is the site of mRNA synthesis and is multi- stranded in nature.
- The action of the basic dyes can result in the bearing of the number of dark bands in the polytene chromosome of varying size and intensity.
- The dark bands are presumed to be formed by the juxtaposition of chromomeres of the different chromonemata of a polytene chromosome.
- They are found in the permanent prophase stage of mitosis.
- In puffs, DNA is uncoiled for rapid transcription of RNA.
- Hence, the main function is the synthesis of RNA and proteins.

## Lampbrush chromosome :



Lampbrush chromosome

**Introduction:**

- Lampbrush chromosomes were first observed in Salamander(amphibian) oocytes in 1882.
- He coined the name because the chromosomes look like the brushes which were used for cleaning the glass chimneys of old fashioned paraffin or kerosene lamps.
- This type of chromosome was observed by Flemming in 1882.
- Lampbrush chromosomes occur in the diplotene chromosomes bivalents of most in animal oocytes.
- It is also found in spermatocytes of several species, a giant cell of Acetabularia, and even in plants.
- These chromosomes are even larger than the polytene chromosomes.

**Detailed explanation:**

- Lampbrush Chromosomes are concerned with vitellogenesis (Yolk formation).
- This is the special kind of synapsed mid prophase or the Diplotene bivalent stage
- This chromosome occurs in pairs containing homologous chromosomes containing the point of contact known as chiasmata.
- The chromatids forming the chromosomes bear a large number of chromomeres which are separated by interchromomeric stretches.
- Many of the chromomeres give out lateral projections or loops which provide a lampbrush-like appearance to the chromosome pair.
- These loops contain one to several transcriptional units which show transcription of mRNA required for the synthesis of the substances for growth and development of meiocytes.
- Some mRNAs produced by lampbrush chromosomes may be stored as informosomes (mRNA + protein) for producing biochemicals during the early development of the embryo.

- The lateral loops are withdrawn followed by the shortening of chromosomes, after the full development of meiocytes.
- The main function is synthesis of RNA and proteins.
- Lampbrush chromosome is a model useful for studying chromosome organization, genome function and gene expression during meiotic prophase.
- This also allows the visualization of the individual transcription units.

# UNIT - II

## Binary Fission

***"Binary fission is a form of asexual reproduction in which an organism divides into two, each part carrying one copy of genetic material."***

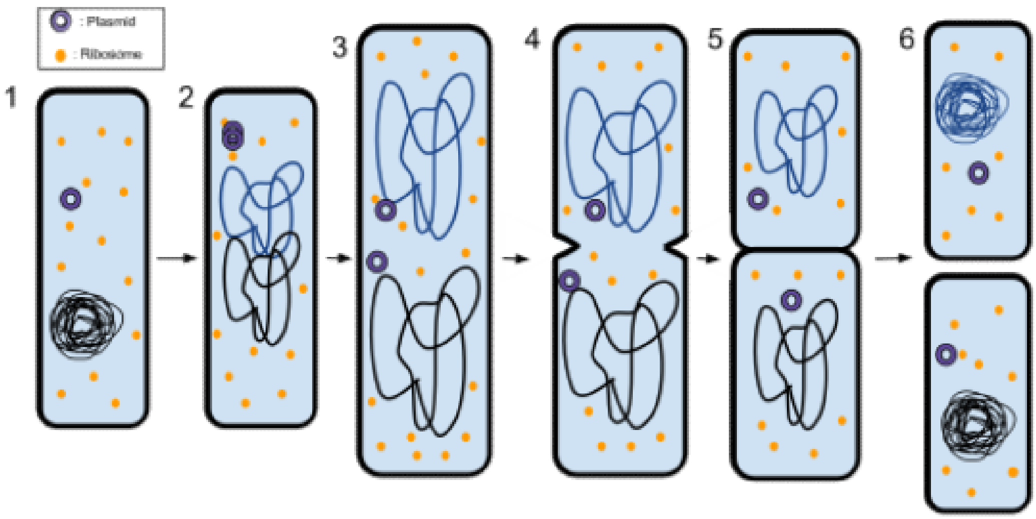
**What is Binary Fission?**

Binary fission is a type of asexual reproduction typically observed in prokaryotes and a few single-celled eukaryotes. In this method of asexual reproduction, there is a separation of the parent cell into two new daughter cells. This process happens with the division and duplication of the parent's genetic matter into two parts. Here, each daughter cell receives one copy of its parent DNA.

It is a primary method of reproduction in prokaryotic organisms. Binary Fission occurs without any spindle apparatus formation in the cell. In this process, the single DNA molecule begins replication and then attaches each copy to various parts of the cell membrane. When the cell starts to get drawn apart, the original (actual) and replicated chromosomes get apart.

However, asexual mode of reproduction has a significant drawback. All resultant cells are genetically identical, mirror copies of each other and the parent cell. Most antibiotics work on this principle. If a parent cell is vulnerable to an antibiotic, then all resultant daughter cells are vulnerable too. If a mutation occurs in their genes, then it can render a particular strain resistant to antibiotics.

Prokaryotes such as E. coli, Archaea as well as eukaryotes such as euglena reproduce through binary fission.




Binary fission is a form of cell division in eukaryotes. In prokaryotes, it is a form of asexual reproduction

**Binary Fission in Bacteria**

The process of binary fission is usually rapid, and its speed varies among species. The time required by bacteria to double the number of cells it has is called doubling time. Furthermore, each species requires specific conditions for its growth. These conditions include pH levels, temperature, oxygen, light, moisture, osmotic pressure.

For instance, mesophiles thrive at moderate temperatures ranging from 20 °C to 45 °C. The ambient temperature of the human body is 37 °C, which means many of the disease-causing bacteria are mesophiles. *Mycobacterium tuberculosis* is the bacterium that causes tuberculosis in humans. It divides every 15 to 20 hours, which is very slow when compared to other pathogenic bacteria such as Escherichia coli, which can divide every 20 minutes.

On the other end of the spectrum are the extremophiles. These bacteria can survive extremely harsh conditions such as high temperatures, high salinity, highly acidic environments and more. For instance, the *Deinococcus radiodurans* is an extremophilic bacteria that can survive a thousand times more radiation than a person can. Under normal circumstances, it can divide every 48 hours. However, when exposed to harsh conditions like drought, it can slow down its growth rate until more favourable conditions arise.

**The steps involved in the binary fission in bacteria are:**

1. 1. **DNA Replication**:

The parent cell's DNA replicates.

2. 2. **Cell Elongation and DNA Segregation**:

The cell grows larger, and the replicated DNA molecules move to opposite ends of the cell, often by being attached to the cell membrane.

3. 3. **Septum Formation**:

A protein ring (FtsZ) forms in the center of the cell, which directs the synthesis of new cell membrane and cell wall material, forming a septum.

4. 4. **Cell Division**:

The septum grows inward, and the cell divides completely into two daughter cells, each with identical genetic material.

**Types of Binary Fission**

Binary fission is classified into different types based on the plane of division:

1. **Simple Binary Fission** – Cell divides in any random plane (e.g., amoeba).
2. **Longitudinal Binary Fission** – Division occurs along the cell's long axis (e.g., euglena).
3. **Transverse Binary Fission** – Division occurs along the short axis (e.g., paramecium).
4. **Oblique Binary Fission** – Division occurs at an oblique angle (e.g., ceratium).

## Importance of Binary Fission

- Ensures rapid population growth in microorganisms.
- Helps bacteria adapt to different environments.
- Plays a crucial role in microbial ecology and human health.
- Some bacteria develop antibiotic resistance through mutations during binary fission.

# Cell Cycle

**cell Cycle Definition**

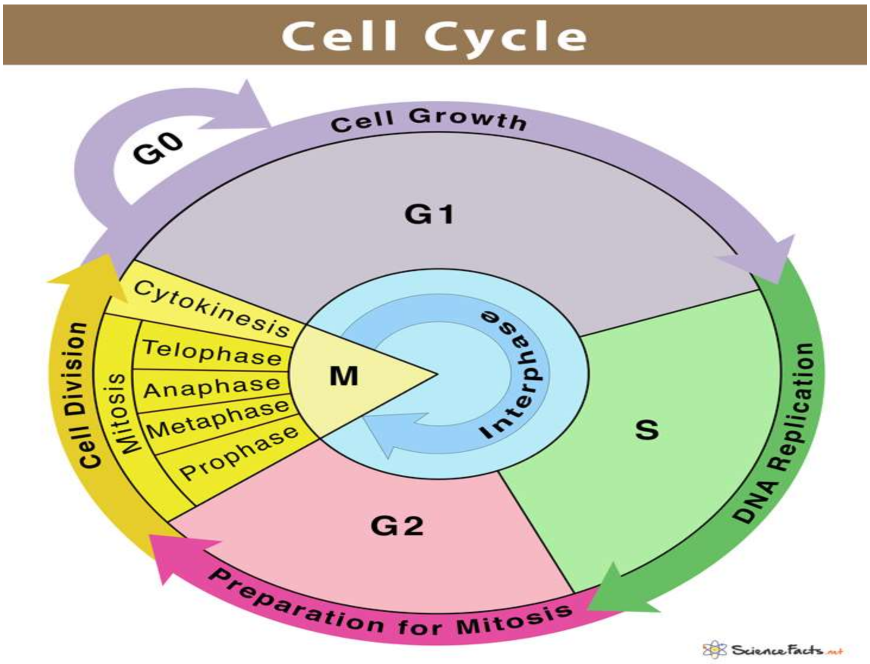
***"Cell cycle refers to the series of events that take place in a cell, resulting in the duplication of DNA and division of cytoplasm and organelles to produce two daughter cells."***

**What is Cell Cycle?**

The cell cycle was discovered by Prevost and Dumas (1824) while studying the cleavage of zygote of Frog. It is a series of stages a cell passes through, to divide and produce new cells.

This entire process where with the help of one single parent cell a new cell population grows and develops is known as the cell cycle.

**Phases of Cell Cycle**




Cell cycle or cell division refers to the series of events that take place in a cell leading to its maturity and subsequent division. These events include duplication of its genome and synthesis of the cell organelles followed by division of the cytoplasm.

Human cells exhibit typical eukaryotic cell cycle and take around 24 hours to complete one cycle of growth and division. The duration of the cycle, however, varies from organism to organism and cell to cell.

A typical eukaryotic cell cycle is divided into two main phases:-

**Interphase**

Also known as the resting phase of the cell cycle; interphase is the time during which the cell prepares for division by undergoing both cell growth and DNA replication. It occupies around 95% time of the overall cycle. The interphase is divided into three phases:-

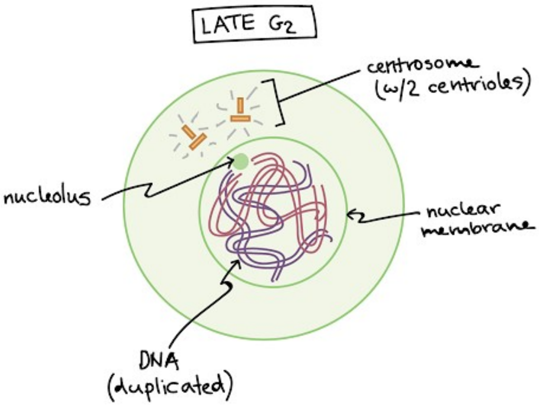
**$G_1$-phase or Pre-DNA synthesis phase**

- It is the longest phase of the cell cycle and is followed by the M phase of the previous cell cycle.
- It is also termed as the "resting phase" as no DNA synthesis takes place during this phase.
- However, during $G_1$ phase, several cell organelles increase in size and cell rapidly synthesizes different types of RNA and proteins.
- Important events like the transcription of three types of RNAs, synthesis of regulatory proteins, enzymes required for DNA synthesis, and tubulin proteins along with other mitotic apparatus take place during this phase.

**S-phase or DNA Synthesis phase**

- S-phase involves the replication of nuclear DNA and the synthesis of histone proteins. The replication of cytoplasmic DNA can take place at any phase in the cell cycle.
- Thus, at the end of the S phase, each chromosome has two DNA molecules and a duplicate set of genes.
- This phase lasts for about 6-10 hours.

**$G_2$-phase or Post DNA synthesis phase**




$G_2$ phase is termed the second gap phase or resting phase of the interphase.

- During this phase, the synthesis of RNA and proteins required for the cell continues.
- Cell division involves the enormous expenditure of energy, thus cell stores ATP in the $G_2$.
- By the end of this phase, the cell enters the division or M-phase of the cell cycle.

# 2.5 Cell Cycle Regulation and Checkpoints

## 1. Overview of the Cell Cycle

The cell cycle is the sequence of events by which a cell grows, duplicates its DNA, and divides. It consists of:

1. **Interphase** (cell growth and DNA replication)
    - **G1 phase (Gap 1):** Cell grows, synthesizes RNA and proteins. Prepares for DNA replication.
    - **S phase (Synthesis):** DNA replication occurs, chromosome duplication.
    - **G2 phase (Gap 2):** Cell continues growth, produces proteins for mitosis, checks DNA for errors.
2. **Mitotic phase (M phase)**
    - **Mitosis:** Division of nucleus (Prophase → Metaphase → Anaphase → Telophase)
    - **Cytokinesis:** Division of cytoplasm to form two daughter cells.

## 2. Importance of Cell Cycle Regulation

- Ensures correct DNA replication and division.
- Prevents uncontrolled cell proliferation (cancer).
- Allows DNA repair and response to cellular stress.

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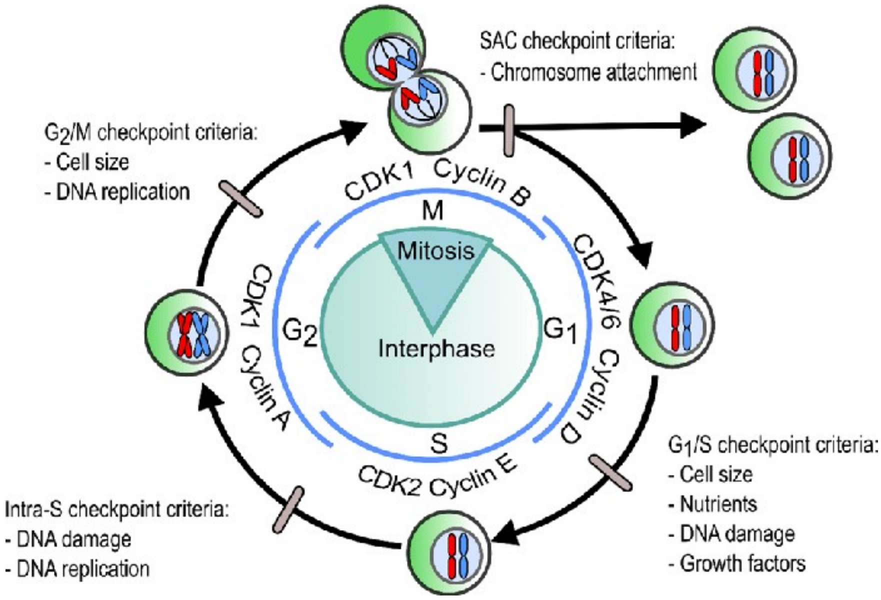
## 3. Key Regulators of Cell Cycle




### A. Cyclins

- Proteins whose concentration fluctuates during the cell cycle.
- Bind and activate cyclin-dependent kinases (CDKs).
- Types:
  - **G1 Cyclins (Cyclin D):** Drive G1 → S transition.
  - **S Cyclins (Cyclin E, Cyclin A):** Drive DNA replication.
  - **M Cyclins (Cyclin B):** Initiate mitosis.

### B. Cyclin-Dependent Kinases (CDKs)

- Serine/threonine kinases activated by cyclins.
- Phosphorylate target proteins to progress the cell cycle.
- Examples:
  - **CDK4/6:** Activated by Cyclin D for G1 progression.
  - **CDK2:** Works with Cyclin E/A for G1 → S transition.
  - **CDK1:** Works with Cyclin B for G2 → M transition.

### C. CDK Inhibitors (CKIs)

- Proteins that inhibit cyclin-CDK complexes to halt cell cycle.
- Examples:
    - **p21, p27, p57:** Inhibit CDKs during DNA damage or stress.
    - **p16:** Blocks CDK4/6, prevents G1 progression.

---

## 4. Cell Cycle Checkpoints

Checkpoints monitor and control progression; they prevent errors.

### A. G1/S Checkpoint (Restriction Point)

- **Purpose:** Determines if the cell is ready for DNA replication.
- **Checks:** DNA integrity, cell size, nutrients, growth signals.
- **Key regulators:** p53, p21, Rb protein, Cyclin D/CDK4/6.
- **Mechanism:**
    - If DNA is damaged → p53 activates p21 → inhibits Cyclin E/CDK2 → cell cycle arrest → DNA repair or apoptosis.

### B. G2/M Checkpoint

- **Purpose:** Ensures DNA replication is complete and intact before mitosis.
- **Checks:** DNA damage, replication completeness.
- **Key regulators:** Cyclin B/CDK1, p53, Wee1 kinase.
- **Mechanism:** DNA damage activates ATM/ATR kinases → activate Chk1/Chk2 → inhibit Cdc25 phosphatase → block activation of Cyclin B/CDK1 → G2 arrest.

### C. Spindle Assembly Checkpoint (SAC) / M Checkpoint

- **Purpose:** Ensures all chromosomes are attached to spindle before anaphase.
- **Checks:** Proper chromosome attachment to spindle microtubules.
- **Key regulators:** Mad2, BubR1, APC/C (Anaphase-Promoting Complex/Cyclosome).
- **Mechanism:** Unattached kinetochores inhibit APC/C → prevents degradation of securin → blocks separase → halts sister chromatid separation.

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## 5. Other Regulatory Mechanisms

- **DNA Damage Response (DDR):** p53-mediated pathway triggers repair, arrest, or apoptosis.
- **Growth Factor Signaling:** Cyclin D expression is stimulated by mitogens.
- **Tumor Suppressors:** p53, Rb; halt cell cycle on stress/damage.
- **Proto-oncogenes:** Cyclins, CDKs; promote progression.

### 6. Summary Table of Checkpoints

| Checkpoint | Phase | Monitors | Key Regulators | Outcome if Failed |
|---|---|---|---|---|
| G1/S | G1 → S | DNA damage, nutrients, size | p53, p21, Rb, CDK2 | Arrest, DNA repair, apoptosis |
| G2/M | G2 → M | DNA replication, DNA damage | Cyclin B/CDK1, p53 | Arrest, repair |
| Spindle Assembly | M phase | Chromosome attachment | Mad2, BubR1, APC/C | Halt anaphase |

# MITOSIS

**Mitosis is the process of cell division in which one cell gives rise to two genetically identical daughter cells, resulting in cell duplication and reproduction.**

- The number of chromosomes is preserved in both the daughter cells.
- Mitosis is a short period of chromosome condensation, segregation, and cytoplasmic division.
- The mitosis occurs in the somatic cells, and it is meant for the multiplication of cell numbers during embryogenesis and blastogenesis of plants and animals.
- As a process, mitosis is remarkably similar in all animals and plants.

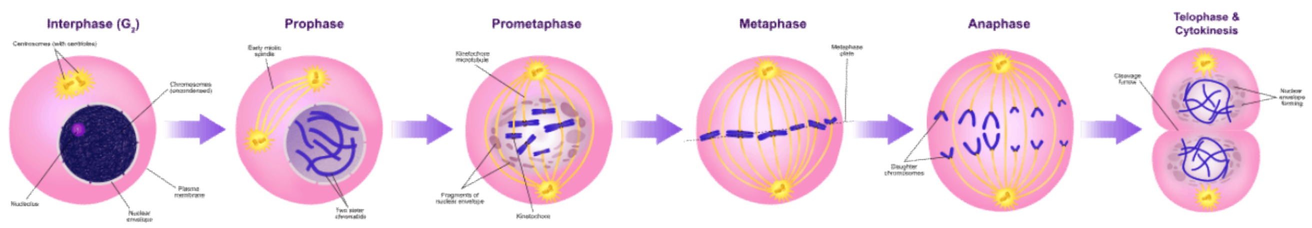
### Importance of Mitosis

The process of mitosis is significant in both cell division as well as cell reproduction. Some of the major significances/purposes are given below:

1. Continuous mitosis results in the increase in the number of cells enabling the organism to grow from a single cell to a complex living organism.
2. Different cells in the body like the cells on the skin and red blood cells are continuously replaced by mitosis. About $5\times10^9$ cells are formed per day in humans via mitosis.
3. Mitosis is also involved in the repairmen and regeneration of body structures like in the starfish.
4. In multiple organisms, mitosis is the method of asexual reproduction.

### Stages of mitosis

Mitosis is a part of the cell cycle and is preceded by the S phase of interphase and usually followed or accompanied by cytokinesis. Replication of chromosomes and synthesis of proteins required for spindle fiber formation are formed prior to the onset of mitosis.

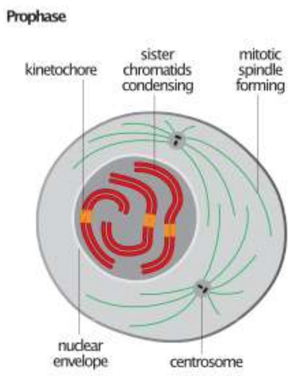



Mitosis is divided into the following phases based on the completion of one set of activities and the onset of the other.

**1. [Interphase]**

- Interphase is a part of the cell cycle where the cell copies its DNA as preparation for the M phase (mitotic phase).
- In interphase, metabolism of the cell increases, and it is often termed the most active phase of the cell cycle.
- A series of metabolic changes occur during this phase, all of which are divided into three subgroups.

**2. [Prophase]**



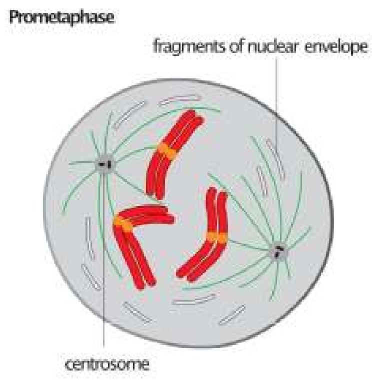


Prophase is the first stage of mitosis which is characterized by the appearance of thin-thread like condensing chromosomes.

- During prophase, the cell becomes spheroid while the cytoplasm becomes more refractile and viscous and pale.
- The chromosome in the prophase is composed of two coiled filaments, the chromatids, which are the result of the replication of DNA during the S phase.
- As prophase progresses, the chromatids become shorter and thicker, and two sister chromatids of each chromosome are held together by a special DNA-containing region, called the centromere.
- Similarly, the chromosomes approach the nuclear envelope, causing the central space of the nucleus to become empty.
- In the meantime, two pairs of centrioles surrounded by microtubules radiating in all directions migrate to opposite poles of the cell.

- Lastly, during prophase, the nucleolus gradually disintegrates, and this marks the end of prophase.
- However, in some primitive classes of plants and animals, the nuclear envelope does not dissolve during mitosis.

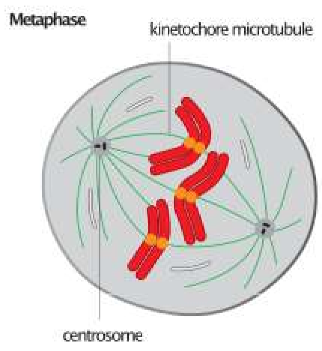
### 3. Prometaphase

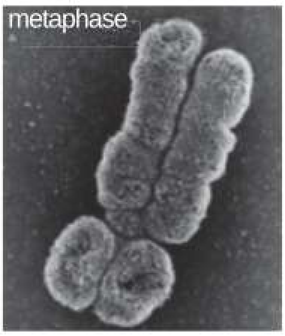



Prometaphase is initiated with the breakdown of the nuclear envelope, which enables the interaction of spindle fibers with the chromosomes.

- At this stage, the chromosomes are violently rotated and oscillated back and forth between the spindle poles because their centromeres are capturing the ends of microtubules and are being pulled by the captured microtubules.
- By the end of prometaphase, the sister chromatids are attached to the spindle fibers on the opposite ends and are held on the metaphase plate.

### 4. Metaphase

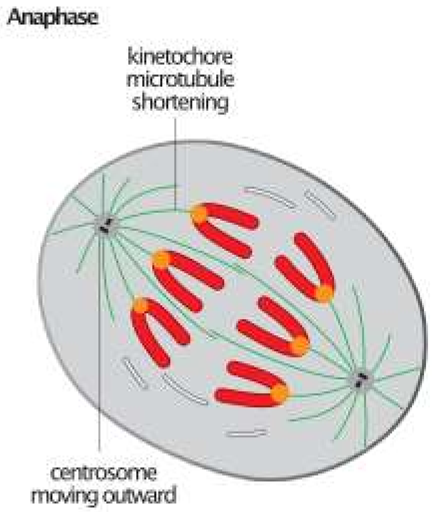


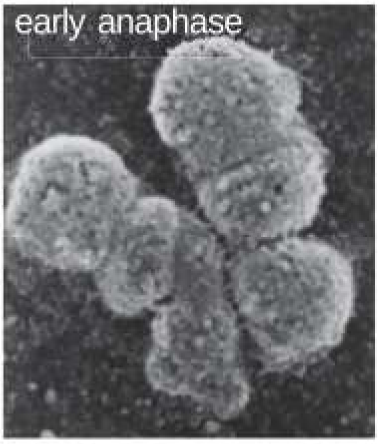




During metaphase, the chromosomes are shortest and thickest.

- Their centromeres of the sister chromatids occupy the plane of the equator forming a metaphase plate, and the arms remain directed towards the poles.
- Two chromatids of a chromosome repulse each other with the microtubules remaining stationary and under tension.

**5. Anaphase**




The anaphase begins abruptly with the synchronous splitting of each chromosome into its sister chromatids, called daughter chromosomes, separating for the centromere.

- The splitting of each centromere during prophase is caused by an increase in cytosolic $Ca^{2+}$.
- In anaphase, there is a movement of chromatids towards the pole due to the shortening of the microtubules.
- During their poleward migration, the centromeres remain forward so that the chromosomes characteristically appear U, V or J- shaped.
- Interzonal fibers expand and support the movement of chromosomes towards the pole.
- A total of 30 ATPs are required to carry chromosomes to the poles.
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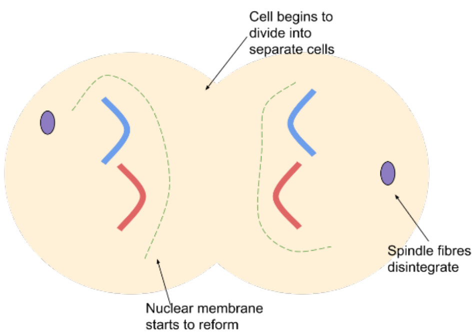
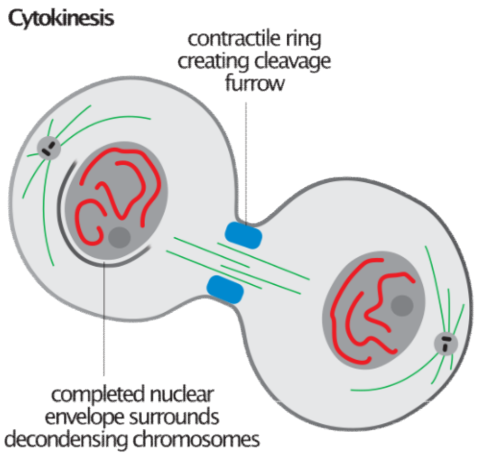
**6. Telophase**




- The end of the migration of the daughter chromosomes to the poles marks the beginning of the telophase
- During telophase, the events of prophase occur in reverse sequence.

- A nuclear envelope reassembles around each group of chromosomes to form two daughter nuclei.
- Events like the disappearance of mitotic apparatus, reduction in the viscosity of cytoplasm followed by synthesis of RNA take place during telophase.
- The chromosomes resume their long, slender, extended form and the nucleolus reappears at the end of telophase.

**7. Cytokinesis**

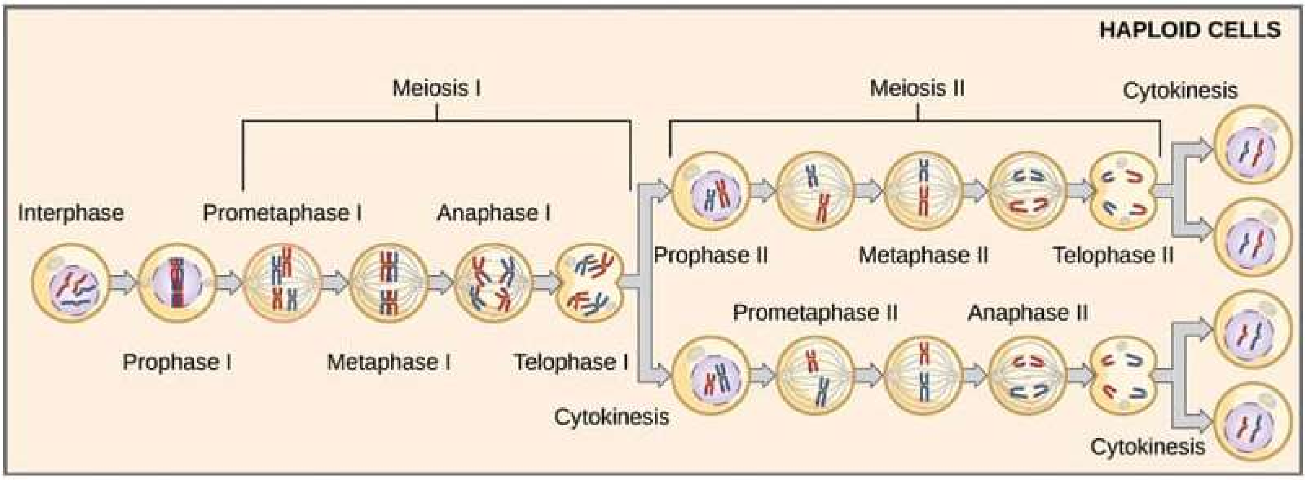



- Cytokinesis is the division of cytoplasm which is followed by mitosis, resulting in the formation of two separate daughter cells.
- Cytokinesis usually begins in anaphase and continues through telophase and into interphase.
- In animals, cytokinesis occurs through constriction and furrow formation.
- The first sign of cleavage in animal cells is constriction of the plasma membrane during anaphase.
- The constriction invariably occurs in the plane of the metaphase plate, at right angles to the long axis of the mitotic spindle apparatus.
- The constriction grows more in-depth from the outside to the inside, and ultimately a cell divides into two daughter cells.
- In plants, however, cytokinesis occurs by cell plate formation as constriction is not possible due to the presence of a rigid cell wall.
- Golgi apparatus arrange themselves on the equator to form phragmoplast, which later forms the cell plate in plants.

# Meiosis

**Meiosis is a type of cell division in sexually reproducing eukaryotes, resulting in four daughter cells (gametes), each of which has half the number of chromosomes as compared to the original diploid parent cell.**

- The haploid cells become gametes, which by union with another haploid cell during fertilization defines sexual reproduction and formation of a new generation of diploid organisms.
- Meiosis occurs in the germ cells of sexually reproducing organisms.
- In both plants and animals, germ cells are localized in the gonads, but the time at which meiosis takes place varies among different organisms.




## IMPORTANCE of Meiosis

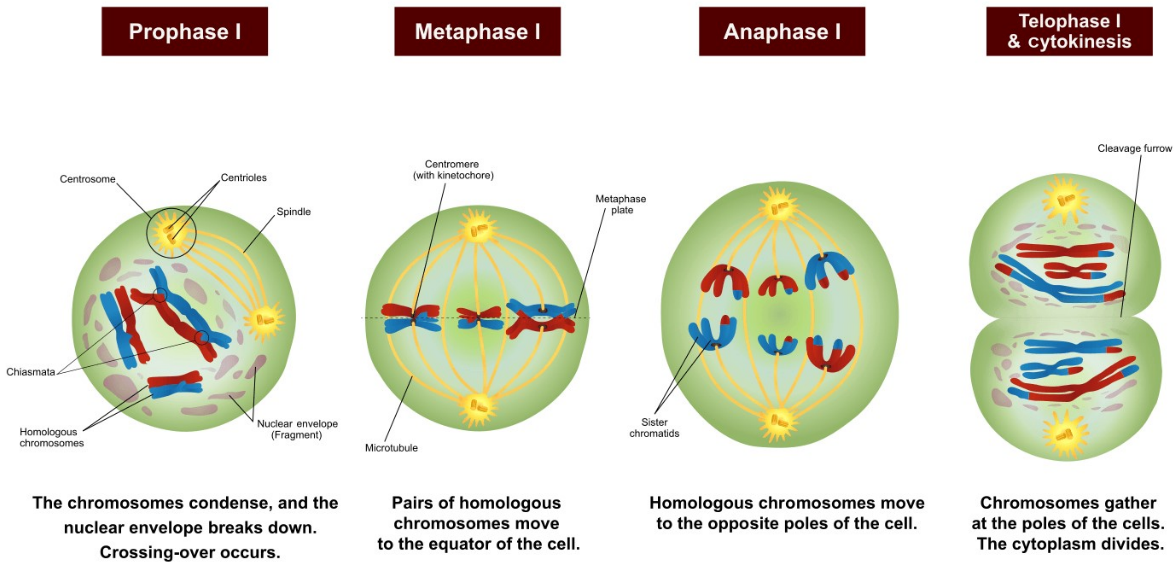
The process of meiosis is essential for all sexually reproducing organisms for the following reasons:

1. The meiosis maintains a constant number of chromosomes in sexually reproducing organisms through the formation of gametes.
2. By crossing over, the meiosis results in the exchange of the genes and, thus, causes the genetic variations among the species. These variations are the raw materials of the evolutionary process.

## Stages/Phases of Meiosis

- Meiosis is composed of two rounds of cell division, namely Meiosis I and Meiosis II.
- Each round of division contains a period of karyokinesis (nuclear division) and cytokinesis (cytoplasmic division).

# Meiosis - I

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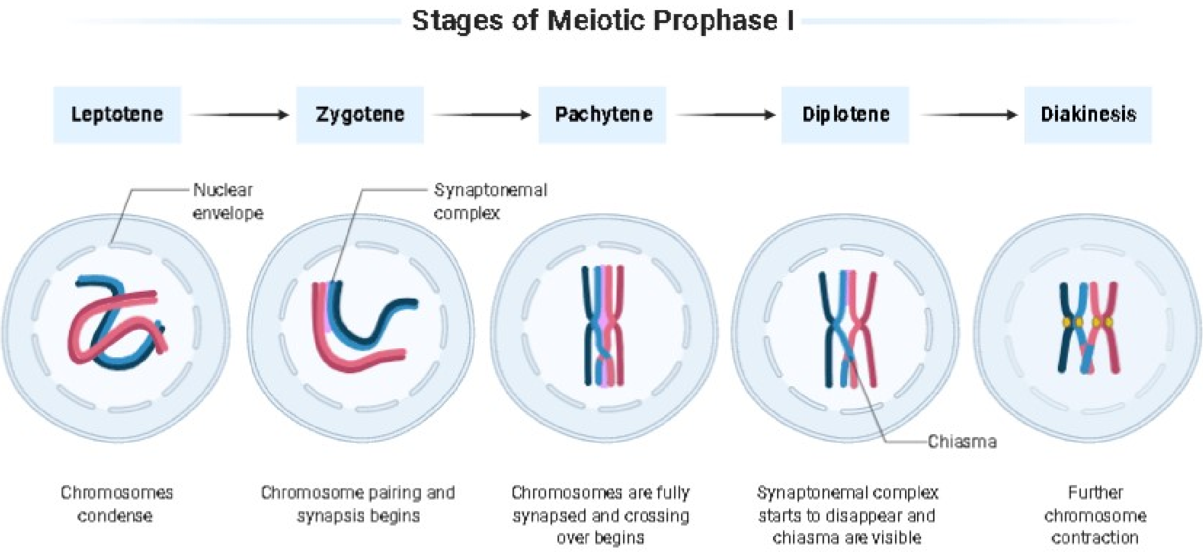
Meiosis I consists of the following steps:

## Interphase

- Just like mitosis, meiosis also consists of a preparatory phase called interphase.
- The interphase is characterized by the following features :
- The nuclear envelope remains intact, and the chromosomes occur in the form of diffused, long, coiled, and indistinctly visible chromatin fibers.
- At the beginning of the first meiotic division, the nucleus of the dividing cell starts to increase in size by absorbing the water from the cytoplasm, and the nuclear volume increases about three folds.

### 1. Prophase I

This is the longest and most complex phase, characterized by key events that ensure genetic diversity. It is subdivided into five substages:




- **Leptotene (Leptonema): "Thin Thread"**
  - Chromosomes condense and become visible as thin threads.
  - The nuclear envelope begins to break down.
  - Centrosomes move to opposite poles.
- **Zygotene (Zygonema): "Paired Threads"**
  - **Synapsis** occurs: Homologous chromosomes pair up precisely, gene for gene, forming a **bivalent** (a pair of homologous chromosomes) or a **tetrad** (which refers to the four chromatids involved).
  - The **synaptonemal complex**, a protein structure, forms between homologues to hold them together.
- **Pachytene (Pachynema): "Thick Threads"**
  - Chromosomes continue to condense and become shorter and thicker.
  - **Crossing Over** occurs: Non-sister chromatids of homologous chromosomes exchange corresponding segments of DNA.
  - This creates new combinations of genes on chromosomes, a crucial source of **genetic variation**.
  - The points of crossing over are visible as **chiasmata** (singular: chiasma).
- **Diplotene (Diplonema): "Two Threads"**
  - The synaptonemal complex dissolves, but the homologous chromosomes remain attached at the chiasmata.

    - The chromosomes are clearly seen as double structures (sister chromatids).
- **Diakinesis: "Moving Through"**
    - Chromosomes reach maximum condensation.
    - The nucleolus disappears.
    - The nuclear envelope fully breaks down.
    - Spindle fibers from the centrosomes begin to attach to the kinetochores of the chromosomes.

### 2. Metaphase I

- The tetrads (pairs of homologous chromosomes) line up at the **metaphase plate** (the equator of the cell).
- This alignment is random, with each pair orienting independently—this is called **Independent Assortment**.
- Spindle fibers from opposite poles attach to the kinetochore of one chromosome from each homologous pair (each chromosome still has two sister chromatids).

### 3. Anaphase I

- Homologous chromosomes are **pulled apart** and move toward opposite poles of the cell.
- **Crucially, the sister chromatids remain attached at their centromeres** and move together as a unit.
- This is the step that reduces the chromosome number from diploid to haploid.

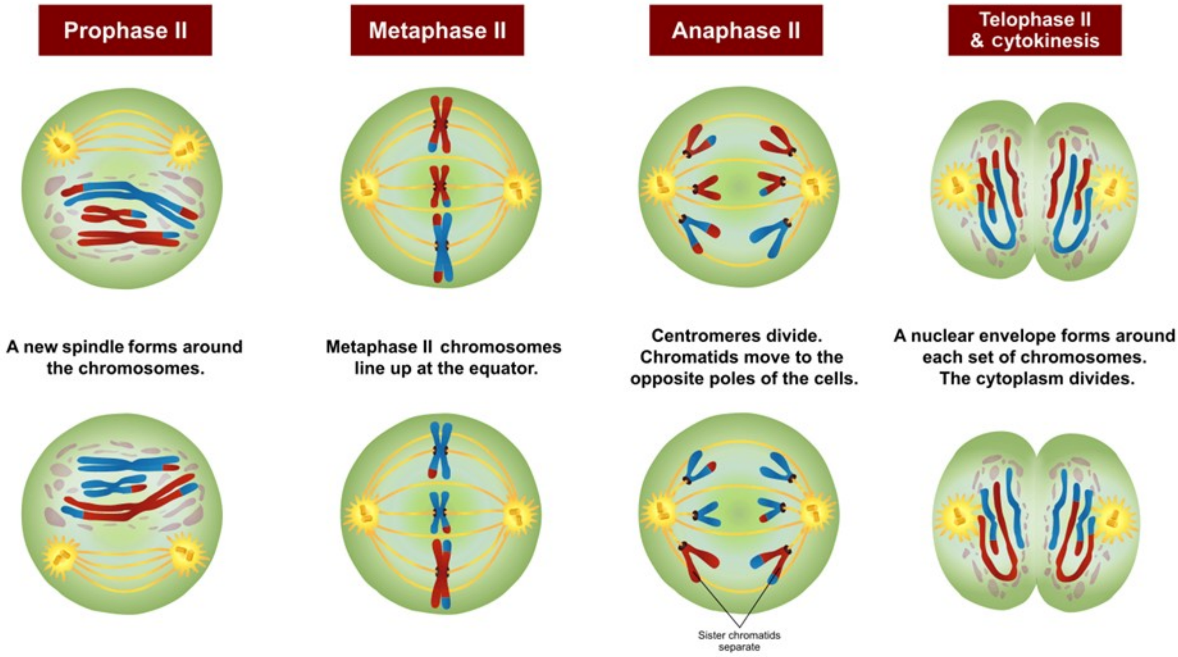
### 4. Telophase I

- The separated homologous chromosomes arrive at opposite poles.
- In some cells, the nuclear envelope may re-form around each set of chromosomes.
- Chromosomes may decondense slightly.

### Cytokinesis I

- In animals, cytokinesis occurs by the constriction of the cell membrane while in plants, it occurs through the formation of the cell plate, resulting in the creation of two daughter cells

- ## Meiosis II: The Equational Division




- The goal of Meiosis II is to **separate sister chromatids**, much like in mitosis. It does *not* reduce the chromosome number further. Instead, it takes the two haploid cells from Meiosis I and splits them into four haploid gametes.
- **Important Starting Point:** The two cells that enter Meiosis II are **haploid (n)**, but their chromosomes are still duplicated (each consists of two sister chromatids). Meiosis II resolves this.

- **The Phases of Meiosis II (Occurs in both cells from Meiosis I)**
- There is **no S phase (no DNA replication)** between Meiosis I and Meiosis II.
- **1. Prophase II**
- The nuclear envelope (if it re-formed) breaks down.
- Chromosomes, still composed of two sister chromatids, re-condense.
- The spindle apparatus begins to form in each of the two haploid cells.
- **2. Metaphase II**
- Chromosomes line up **single-file** along the metaphase plate.
- This is identical to metaphase in mitosis.
- Spindle fibers from opposite poles attach to the kinetochores of **each sister chromatid**.
- **3. Anaphase II**
- The **sister chromatids are pulled apart** (disjoin).
- The separated chromatids, now called individual chromosomes, move to opposite poles.

- **Telophase II**
- The chromatids migrate to the opposite poles and now known as chromosomes.
- The endoplasmic reticulum forms the nuclear envelope around the chromosomes, and the nucleolus reappears due to the synthesis of ribosomal RNA.
- **Cytokinesis II**
- The process of cytokinesis is identical to cytokinesis I resulting in the division of cytoplasm for each of the four daughter cells formed.

# senescence

The plants or their organs like all other living organisms have a certain span of life during which they develop, grow, attain maturity and after some time at the end die. But prior to death, distinctive but natural deteriorative processes occur in them in growth and synthetic activities.

These deteriorative processes that naturally terminate their functional life are collectively called as senescence and the plants or plant organs at this stage are called as senescent. These deteriorative processes may terminate in death either gradually or abruptly depending upon the plant. Senescence is a normal energy dependent developmental process which is controlled by plants own genetic programme and the death of the plant or plant part consequent to senescence is called as programmed cell death (PCD).

Senescence is not confined only to whole plant. It may be limited to a particular plant organ such as leaf and flowers or cells such as phloem and xylem or cell-organelles such as chloroplasts and mitochondria etc. Senescence is closely associated with the phenomenon of aging and both are sometimes considered as the same by many workers. But according to Medawar (1957), the term senescence should be used to refer to natural changes towards termination of life while 'aging' to refer to changes in time without reference to the natural development of death.

**Leopold (1961) has recognised 4 types of senescence patterns in whole plant (Fig17.41) which are as follows:**

**1. Overall Senescence:**

This type of senescence occurs in annuals where whole of the plant is affected and dies.

**2. Top Senescence:**

This is represented by perennial herbs where senescence occurs only in the above ground parts, the root system and underground system remaining viable.

**3. Deciduous Senescence:**

This type of senescence is less drastic and takes place in woody deciduous plants. Here senescence occurs in all the leaves simultaneously but the bulk of the stem and root system remains alive.

**4. Progressive Senescence:**

This is characterized by gradual progression of senescence and death of leaves from the base upwards as the plant grows. (The senescence of the entire plant after a single reproductive cycle is also known as monocarpic senescence) Senescence can best be studied in leaves or similar other organs of plants e.g., cotyledons, sepals, petals etc. or cell organelles like isolated chloroplasts.

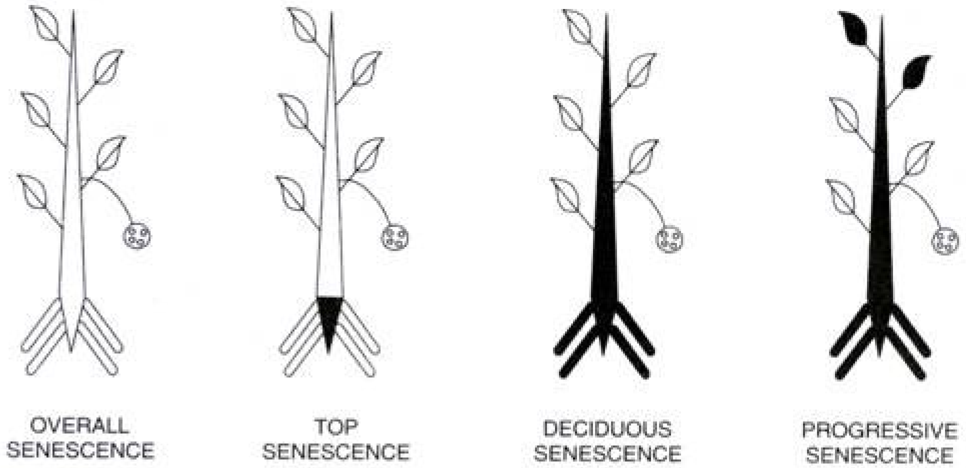


**Fig. 17.41.** Different senescence patterns in plants. Dying parts are unshaded.

i. Senescing cells and tissues are metabolically very active and an ordered series of cytological and biochemical events occur during senescence.

ii. Senescence is characterised by increased respiration, declining photosynthesis and an orderly disintegration of macromolecules.

iii. At the cellular level, chloroplasts are the first organelles to be disintegrated. Nuclei remain structurally and functionally intact until the last stage of senescence. Meanwhile, other cell organelles and bio-membranes also gradually deteriorate.

iv. Expression of senescence down-regulated genes (SDGs) decreases. Such genes encode proteins in photosynthesis and other biosynthetic processes. Concentration of growth promoting hormones especially cytokinins decline.

v. Expression of senescence associated genes (SAGs) increases. Such genes encode hydrolytic enzymes such as proteases, ribonucleases and lipases as well as enzymes involved in biosynthesis of deteriorative hormones such as abscisic acid (ABA) and ethylene.

vi. Some of the SAGs have secondary functions in senescence that are useful to plant. These genes encode enzymes that are involved in conversion and remobilization of nutrients and substrates from senescing tissues and their reallocation to other parts of the plant that survive (i.e., not senescing).

vii. Brilliant Colours are developed in leaves of many plants during senescence.

viii. This is due to degradation of chlorophylls, resulting in unmasking of more stable carotenoid pigments.

ix. Towards the end of senescence, the cells and tissues also lose respiratory control.

Several environmental factors especially those which suppress normal plant growth also tend to enhance the rate of senescence. These are deficiency of soil nutrients, high temperatures, water deficit, darkness etc. In many plants on the other hand, removal of flowers, fruits and vegetative growing points can markedly delay the senescence of leaves. The role of externally supplied cytokinins in delaying senescence especially in detached plant parts is also well established.

# Necrosis

Necrosis is a cell tissue that is generated during the injury. It is a death tissue formed and has no reverse action. With the impact of injury to the skin or bone, the amount of blood supply will reduce gradually. Due to the lack of blood supply, necrosis tissues were formed. The death of cells caused by noxious stimuli.

Let's get more ideas on necrotic tissue along with noxious stimuli.

The agents of noxious stimuli are -

- bacteria
- parasites
- viruses
- fungi

The formation of necrosis is due to various reasons. The major reasons are -

oxygen deprivation or hypoxia, and extreme environmental conditions such as heat, radiation, or exposure to ultraviolet irradiation, etc

**Types of Necrosis**

By observing the necrosis meaning, it is clear that the necrosis forms due to a single reason. But, the variation in types of necrosis can be found when the cells die due to necrosis. Those types classified by appearance are -

- Liquefactive necrosis
- Coagulative necrosis

**Liquefactive Necrosis:-**

Is also known as colliquative necrosis. It has a microscopic appearance. Here the dead tissue is dissolved or transformed into a liquid or viscous fluid either partially or completely. All the transformation can be done within the hours.

**Coagulative Necrosis:-**

It is completely different from the about type. It is a macroscopic appearance, and the result can be observed after several days of cell death. It has a default pattern connected to all parts of the body using ischemia or hypoxia except the brain.

Besides these two types, there is another classification based on morphological patterns. They are -

- caseous necrosis
- fibrinoid necrosis

- fat necrosis
- Gangrenous necrosis

**Caseous Necrosis:-**

This is a unique type of necrosis. It is found only in tuberculosis patients.

**Fibrinoid Necrosis:-**

It has a damaged vascular pattern. It can be observed due to deficiency of immune, rickettsia, autoimmunity, immune complex infections, etc. It is also known as avascular necrosis

**Fat Necrosis:-**

The other name is acute tubular necrosis. Because it is caused due to acute inflammation of tissues. They affect several adipocytes and damage the enzymes required for digestion and usually observed in the breast and pancreas.

**Gangrenous Necrosis:-**

This type of necrosis is usually observed in the lower and upper parts of limbs. The affected area of skin turns into black color. The symptoms of both liquefactive necrosis and

coagulative necrosis was found.

# APOPTOSIS

- PROCESS OF PROGRAMMED CELL DEATH
- ENERGETIC PROCESS
- GENETICALLY CONTROLLED

BIOCHEMICAL EVENTS DURING APOPTOSIS

- A) CYTOSKELETON DEGRADATION
- CELL SHRINKAGE
- BLEBBING
- NUCLEAR DISAMBLE
- DNA FRAGMENTATION

IN HUMANS (ADULTS): 50 – 70 BILLION CELLS DIE DUE TO APOPTOSIS IN A DAY

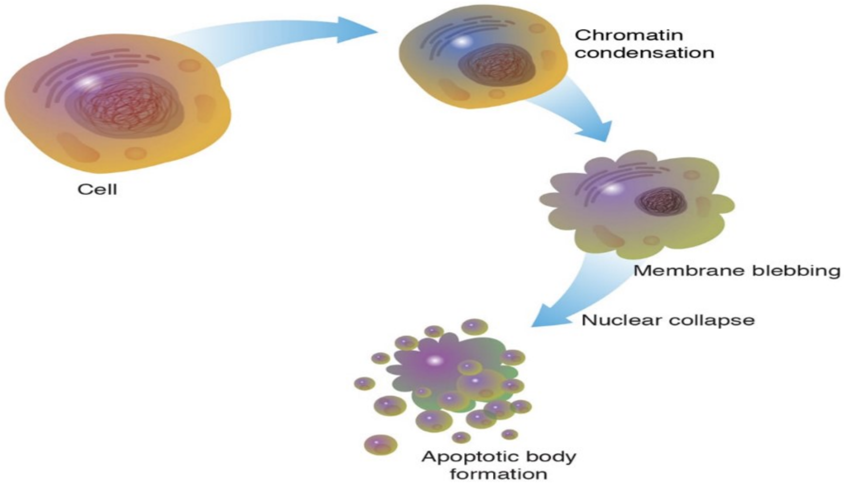
8 – 14 YEARS AGE IN CHILDREN : 20 – 30 BILLION CELLS DIE IN A DAY

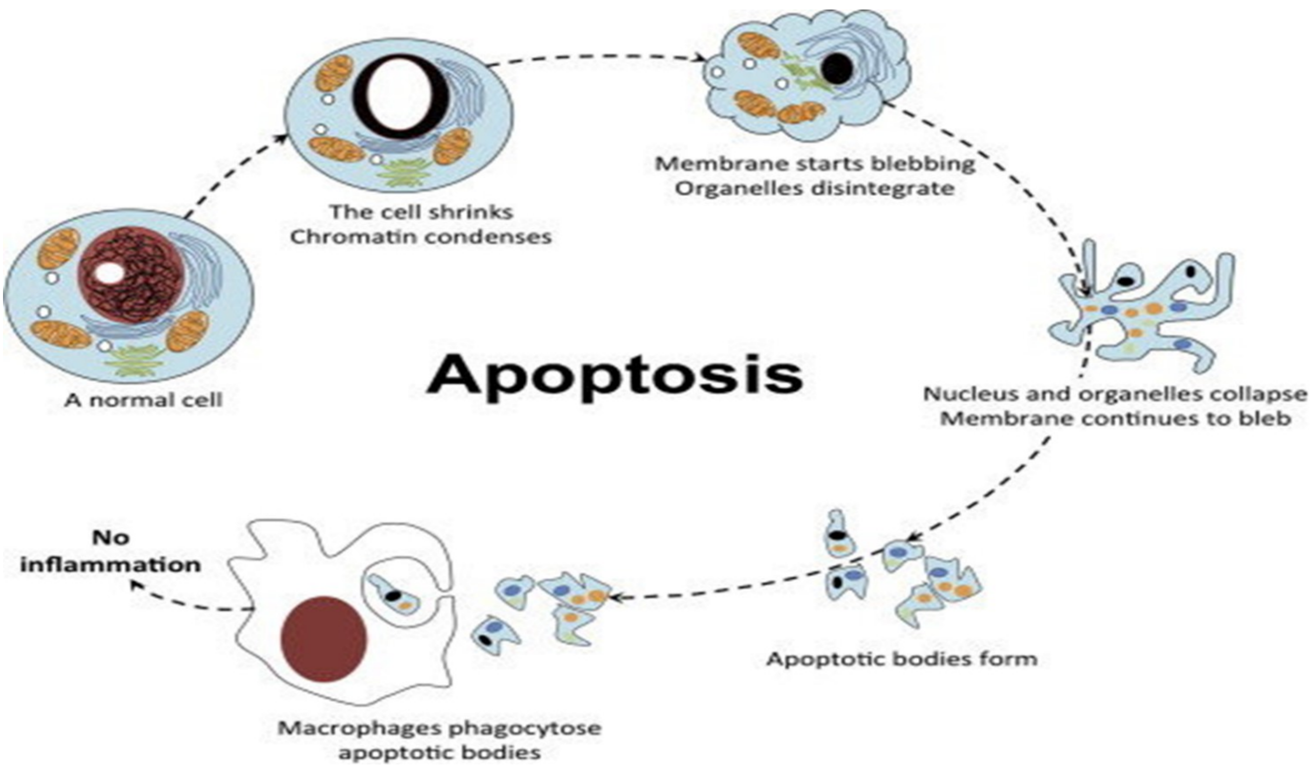
HISTORY

CARL VOGT (1842) GERMAN SCIENTIST IST DESCRIBED APOPTOSIS

THE TERM APOPTOSIS IST COINED BY KERR IN 1972

## APOPTOSIS

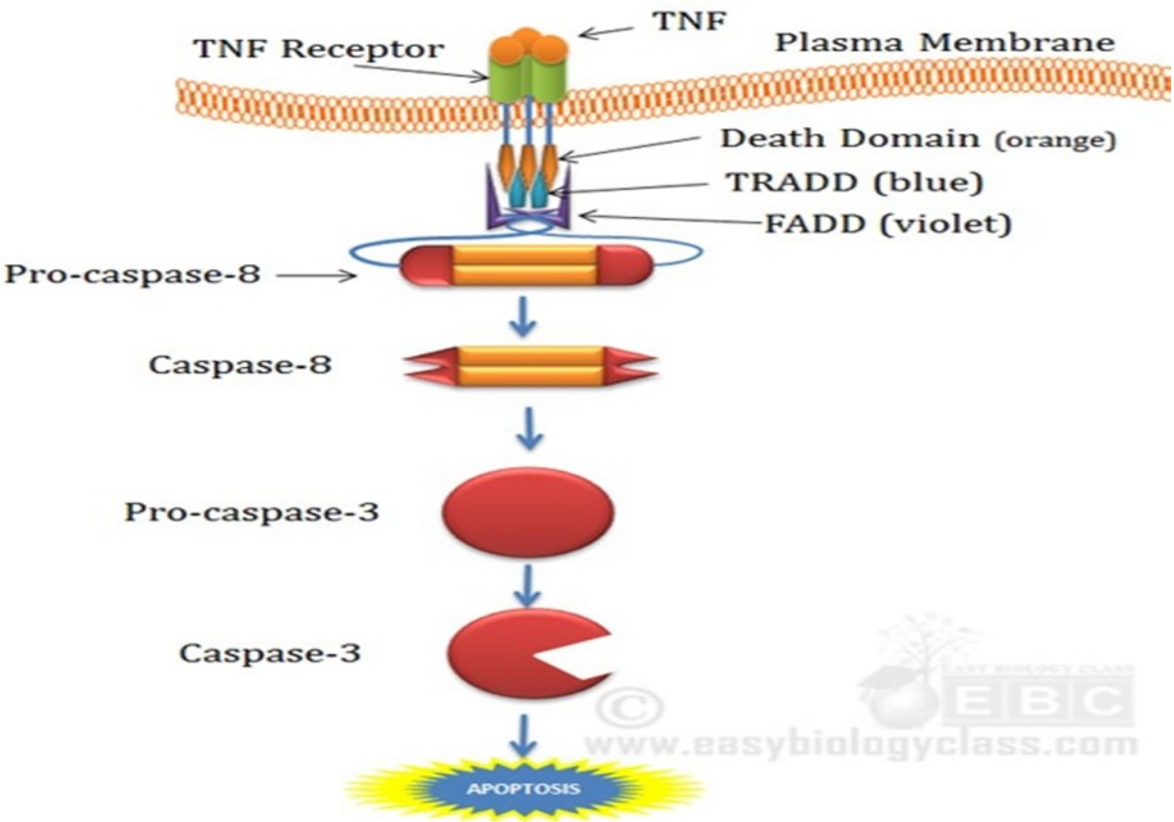



# PATHWAYS

- EXTRINSIC
- INTRINSIC

- **EXTRINSIC PATHWAY**
- EXTRINSIC SIGNALLING PATHWAY PRODUCES TRANSMEMBRANE DEATH RECEPTORS WHICH ARE MEMBERS OF TUMOR NECROSIS FACTORS (TNF)
- DEATH RECEPTOR BINDS TO PRO-APOPTOTIC LIGANDS SUCH AS apo3L, apo2L
- THESE INTERACTION ACTIVATES INTIATOR CASOASES 8, ENZYME WHICH PROTEASES IN NATURE & THEN ACTIVAATES THE CASPASES 3, 6, & 7.
- LEADS TO DEGRADATION OF CELLULAR FUNCTION & FINALLY CAUSES APOPTOSIS




Extrinsic Pathway of Apoptosis

## INTRINSIC PATHWAY

- INTRINSIC PATHWAY PRODUCES P53 PROTEIN, WHERE NOXA & BAK CONVERTS INTO BAX
- BAX BINDS TO MITOCHONDRIA
- PRODUCES cys C + PROCASPASE 9
- APOPTOSOME FORMATION
- ACTIVATES EFFECTOR CASPASES 3,7

- LEADS TO BLEBBING,
- NUCLEAR FRAGMENTATION

APOPTOSIS

## Proteins / factors involved

BAX - Bcl 2 associated X protein

BAK - Bcl 2 associated killer protein

Apaf - apoptotic protease activating factor